

## 4.2 Actinium-227

Actinium-227 is a radioactive decay product in the naturally occurring actinium series (see Section 4.1.2.2). Waste buried in the SDA contained only a small amount of Ac-227 at the time of disposal; however, Ac-227 inventories will increase over time through ingrowth attributable to isotopes in the actinium series. After 1,000 years, approximately 0.1 Ci of Ac-227 would be present. Actinium-227 has not been detected in the SDA because it has not been a targeted analyte. Actinium-227 decays by beta emission and has a half-life of  $2.18 \times 10^4$  years. Because the inventory is primarily due to ingrowth, a density map is not provided for Ac-227. Though Pu-239 also is a predecessor, inventories for Ac-227 would be produced primarily by U-235 (see Section 4.14). Figure 4-21 illustrates the densities of U-235 in buried waste.

## 4.3 Americium-241

Americium-241 is an anthropogenic transuranic (TRU) radionuclide that is a decay product of Pu-241 (see Figure 4-2). It decays by the emission of alpha particles and has a 432.7-year half-life. This section summarizes americium monitoring data for all media. Data in this section are evaluated against comparison concentrations in Table 4-1.

**CAVEAT:** *Some low-level detections of Am-241 could be false positives. A study conducted at the Savannah River Site shows that the occurrence of false positive results for Am-241 can be fairly common at commercial laboratories (Kubilius et al. 2004). False positives for Am-241 determined by alpha spectroscopy are attributed to interference from small quantities of natural Th-228 that are not completely removed from the sample during chemical separation (Kubilius et al. 2004).*

### 4.3.1 Waste Zone

Approximately  $2.30 \times 10^5$  Ci of Am-241 was buried in the SDA (through 1999), and an additional 0.44 Ci is projected to be added by 2009, for a total of  $2.30 \times 10^5$  Ci. Figure 4-2 illustrates the densities of Am-241 in buried waste, and Table 4-4 identifies waste streams containing the majority of Am-241 activity. The primary source of Am-241 in the SDA is Rocky Flats Plant Series 741 sludge (i.e., first-stage wastewater sludge). A portion of Pit 4 is currently being excavated to retrieve targeted waste, including Series 741 sludge (DOE-ID 2004a). An area selected for probing in the central part of Pit 10 was identified as the Americium/Neptunium Focus Area.

**4.3.1.1 Waste Zone Spectral Gamma Logging.** The spectral gamma-logging tool detected Am-241 based on the 662- and 722-keV gamma rays. Of the 135 probe holes logged using this tool, 76 (i.e., 56%) showed Am-241. Of the 4,863 total measurements (i.e., all probes and all depths), 1,068 (i.e., 22%) showed Am-241. The Am-241 detection limits were approximately 35 nCi/g for the 662-keV gamma rays and 65 nCi/g for the 722-keV gamma rays. Maximum and average observed Am-241 levels were 30,449 and 841 nCi/g, respectively. Logging data are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6), because the detection limit, maximum concentration, and average concentration are based on several assumptions, including uniform distribution in the vicinity of measurement points. The 59.5-keV gamma peak was not used because it is too easily attenuated by the casing walls and surrounding soil and waste. The signal would be too weak and lost in the noise. Also, a correction was made to the analysis to exclude Cs-137 (Ba-137m) contributions for the 662-keV peak.

**4.3.1.2 Waste Zone Lysimeter Samples.** Between August 2001 and December 2004, 28 Am-241 analyses were performed on soil-moisture samples collected from 11 waste zone lysimeters in the SDA, with three positive detections. One low-level detection occurred in the Americium/Neptunium Focus Area, and the other two detections occurred in the Depleted Uranium Focus Area. Samples from the Depleted Uranium Focus Area were obtained December 2004, using newly installed GEOPS lysimeters. Concentrations of Am-241 varied from about 1 pCi/g to almost 19,000 pCi/L and were accompanied by high concentrations of Pu-239/240 and very high concentrations of VOCs. These data, along with the brown color and odor, suggest the GEOPS lysimeters are seated within buried waste drums and that the samples are representative of waste product.

#### **4.3.2 Surface**

Between 1994 and 2004, 356 soil samples were collected near RWMC. Based on gamma spectrometry results, 95 samples were evaluated for Am-241; 74 positive detections of Am-241 were found, ranging from  $(4.9 \pm 1.5)\text{E-03 pCi/g}$  at the control location at the main gate in 2002 to  $1.6 \pm 0.2 \text{ pCi/g}$  at Pad A in 1997. All surface soil concentrations were less than the 37-pCi/g RBC for soil used for comparison.

Between 1990 and 2004, 162 vegetation samples were collected from RWMC and control locations. Of 49 samples analyzed for Am-241, 21 were positive detections ranging from  $(5.7 \pm 2.0)\text{E-04 pCi/g}$  at Frenchman's Cabin in 2003 to  $(1.14 \pm 0.20)\text{E-01 pCi/g}$  at RW4 in 1998.

Between 1991 and 2004, 237 samples of surface run-off water were collected from RWMC and control locations. Based on gamma spectrometry analytic results, 103 samples were evaluated for Am-241, resulting in nine positive detections. Positive results ranged from  $(6.6 \pm 1.6)\text{E-02 pCi/L}$  in 1999 to  $9.9 \pm 1.2 \text{ pCi/L}$  in 1997. All surface water run-off concentrations were less than the MCL of 15 pCi/L total alpha used for comparison.

#### **4.3.3 Vadose Zone**

The following subsections discuss distributions of Am-241 in vadose zone cores, soil moisture, and perched water at various depth intervals.

##### **4.3.3.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.**

Americium-241 was detected in two of three samples at concentrations of  $0.014 \pm 0.004$  and  $0.022 \pm 0.007 \text{ pCi/g}$ . Both concentrations slightly exceeded the surficial soil background upper tolerance limit of 0.011 pCi/g but were less than the 37-pCi/g RBC for soil used for comparison (see Table 4-1) (see Section 4.1.4.5).

**4.3.3.2 Vadose Zone Core Samples.** Between 1971 and 2003, 334 core samples were collected during well drilling and analyzed for Am-241, with 34 positive detections. Table 4-9 shows concentration ranges of detections in each depth interval.

Of the 34 positive detections, 32 exceeded the surface soil background upper tolerance limit of 0.011 pCi/g (see Table 4-1). Detection rates were similar in the 0 to 11-m (0 to 35-ft) and 11 to 43-m (35 to 140-ft) depth intervals: 17.2 and 17.4%, respectively. The detection rate of 2.6% was considerably lower for samples collected at depths greater than 43 m (140 ft). Most Am-241 detections were not corroborated by detections of other actinides (e.g., Pu-238 and Pu-239), except for those core samples collected from beneath Pit 5 (i.e., Wells 79-2, D02, and TW1).

Table 4-9. Americium-241 detections in shallow (less than 35 ft) lysimeters.

Americium-241 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																
	2																
	3																
	4																
1998	1																
	2							4.2									
	3					9											
	4																
1999	1			0.8												0.8	
	2																
	3																
	4																
2000	1																
	2			0.3													
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2										1.8						
	3																
	4																
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).																	
		Analysis was performed, but Am-241 was not detected.															
		Am-241 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.3).															

Positive detections were associated with 13 of the 55 samples, with six of the 13 located on the western end of the SDA, and three of the 13 near Pit 5. Eight analyses from Well TW1 at the 31-m (101-ft) depth detected concentrations of Am-241; this confirms the presence of Am-241 at that location and depth. Results from Well 4E at 3 m (10 ft) deep and from Well D02 at 0.5 m (1.5 ft) deep exceed the surface soil background concentration but are lower than the soil RBC of 37 pCi/g used for comparison (see Table 4-1).

The most recent core sampling (FY 2004) focused on the B-C and C-D sedimentary interbeds beneath RWMC. No Am-241 was detected in any of 13 interbed samples. These results are not comparable to previous detections because samples were not collected at the same interbed locations. The only core locations that are near one another are DE4 (2004) and I4D (2000) in the southwestern corner of Pad A, and Am-241 results correlate reasonably well. Although the DE4 result was not a  $3\sigma$  detection, it was a statistical detection (i.e., greater than  $2\sigma$ ), with a measured concentration identical to I4D (i.e.,  $0.020 \pm 0.008$  pCi/g).

**4.3.3.3 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1997 and August 2004, 155 analyses for Am-241 were performed on soil-moisture samples collected from 18 shallow-depth lysimeters near RWMC, resulting in six positive detections. Table 4-9 shows the distribution of Am-241 detections in the shallow-depth lysimeter samples, and Table 4-15 provides the concentration ranges and detection rates. Positive results did not exceed the aquifer MCL of 15 pCi/L (total alpha) used for comparison. The positive detection in January 2004 is suspect because Am-241 has never been detected in Lysimeter Well W08, and the low measured concentration may be a false positive (see caveat in Section 4.3). Figure 4-101 summarizes results for Am-241 in shallow vadose zone samples. Sporadic detections occur, but no trends are apparent for Am-241 in shallow-depth lysimeters.

The concentration of  $9 \pm 2$  pCi/L in Lysimeter PA01:L15 is relatively high compared to positive detections in other samples; however, a duplicate sample did not show detectable Am-241. In addition, 12 other sampling events in Lysimeter PA01:L15 since April 1998 showed no detections. Other lysimeters with positive detections have not had recurring detections, except for 98-5:L39; however, Am-241 has not been detected at that lysimeter location for more than 4 years. Lysimeter wells having the highest concentrations, or more than one detection (i.e., PA01, PA03, and 98-5), are located near Pad A and on the western end of the SDA.

Low concentrations of Am-241 in lysimeter samples collected from wells where Am-241 was detected in vadose zone core samples may be interpreted as evidence of migration. Relatively high detections of Am-241 are detected around Pad A in Lysimeters PA03-L33 and PA01-L15. Sample results may be biased low because of possible Am-241 retention in the porous ceramic cup in the lysimeters (see Section 4.1.6.5).

**4.3.3.4 Lysimeter Samples at Depths from 35 to 140 ft.** Between 1997 and August 2004, 117 analyses for Am-241 were performed on soil-moisture samples collected from 14 intermediate-depth lysimeters near RWMC, with six positive detections. Table 4-10 shows the distribution of Am-241 detections in the intermediate-depth lysimeter samples, and Table 4-15 provides the concentration ranges and detection rates. Sporadic detections occur, but no trends are apparent for Am-241 in intermediate-depth lysimeters.

Positive sample results could not be confirmed by reanalysis because of the limited water sample obtained from lysimeters. Three of the six detections occurred in the vicinity of Pad A and Pit 5 (i.e., Wells D06 and TW1), one occurred at the western end of the SDA (i.e., Well I-1S), and the other two occurred outside the SDA boundary to the southwest (i.e., Well D15).

Lysimeters in Wells D06, D15, and TW1 are porous ceramic cups and may retain a fraction of Am-241 (see Section 4.1.6.5), thus introducing a low bias to these sample results.

Table 4-10. Americium-241 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Americium-241 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
1997	1														
	2														
	3														
	4														
1998	1														
	2														
	3			2.4											
	4														
1999	1	0.8													
	2														
	3														
	4														
2000	1														
	2														1.9
	3														
	4														
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														
2003	1														
	2														
	3														
	4														
2004	1														
	2														
	3	5.1		1.6	6.0										
	4														
Note: The highest result is reported for duplicate samples or reanalysis.															
For comparison, the maximum contaminant level = 15 pCi/L (total alpha).															
Analysis was performed, but Am-241 was not detected.															
Am-241 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.3).															

**4.3.3.5 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Including USGS analyses, 167 analyses for Am-241 were performed on perched water samples, filtered sediment samples, and deep suction lysimeter samples near RWMC between 1974 and August 2004, yielding three detections. Two detections of Am-241 occurred in Well USGS-92 and one in Well IE4. Table 4-11 shows the distribution of Am-241 detections in the deep lysimeter samples, and Table 4-15 provides the concentration ranges and detection rates. Perched water samples are filtered if they contain sediment, and the filtered material also is analyzed for Am-241. None of the filtered sediment was positive for Am-241. Detections are sporadic, with no apparent trends for Am-241 in deep vadose zone lysimeters.

Table 4-11. Americium-241 detections in deep (greater than 140 ft) lysimeters since 1974.

Americium-241																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
1974	3																						
1975	—																						
1976	2																						
1977	1 and 3																						
1978	—																						0.041
1979	3																						
1980	3																						
1981	3																						
1982	1 and 3																						
1983	1 and 3																						
1984	1 and 3																						
1985	1 and 3																						
1986	1 and 3																						
1987	1 and 3																						
1988	1 and 3																						
1989	1 and 3																						
1990	—																						
1991	—																						
1992	1 and 3																						0.14
1993	1																						
1994	—																						

Table 4-11. (continued).

Americium-241 Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
1995	1																						
1996	2																						
1997	1																						
	2																						
	3																						
	4																						
1998	1																						
	2																						
	3																						
	4																						
1999	1																						
	2																						
	3																						
	4																						
2000	1																						
	2																						
	3																						
	4																						
2001	1																						
	2																						
	3																						
	4																						



Table 4-11. (continued).

Americium-241																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
2002	1																						
	2																						
	3																						
	4																						
2003	1																						
	2																						
	3																						
	4																						
2004	1										30												
	2																						
	3																						
	4																						
Note: The highest result is reported for duplicate samples or reanalysis.																							
For comparison, the maximum contaminant level = 15 pCi/L (total alpha).																							
	Analysis was performed for Am-241, but none was detected.																						
	Am-241 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.3).																						

#### 4.3.4 Aquifer

For Am-241, 479 analyses were performed on aquifer samples collected from 16 aquifer wells near RWMC between 1992, when aquifer monitoring for Am-241 began, and May 2004, yielding nine positive detections. None of the detections exceeded the MCL of 15 pCi/L (total alpha). Table 4-12 shows the distribution of Am-241 detections in the ICP aquifer samples, and Table 4-15 provides the concentration ranges and detection rates. Only the October 1997 sample result was confirmed by reanalysis of the original sample. Subsequent samples collected from these wells through August 2004 have not shown positive detections. Historical results for aquifer samples show sporadic detections of Am-241 but no evident trends.

Table 4-12. Americium-241 detections in aquifer wells since October 1992.

Americium-241 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
1993	1																
	2																
	3																
	4																
1994	—																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3																
	4																
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																

Table 4-12. (continued).

Americium-241 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
2000	1																
	2																
	3																
	4											0.027					
2001	1																
	2																
	3																
	4							0.039					0.066				0.058
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis.																	
For comparison, maximum contaminant level = 15 pCi/L total alpha.																	
		Analysis was performed, but Am-241 was not detected.															
		Am-241 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.3).															
		Well is out of service. Well was rendered inoperable after repairs were unsuccessful.															

Between 1972 and April 2003, 525 analyses for Am-241 on eight USGS aquifer wells in the vicinity of RWMC yielded 23 detections; however, 21 of the 23 samples may have been cross-contaminated (see Section 4.1.6.4). All but two of the USGS detections occurred between 1972 and 1974, shortly after the wells were drilled and installed (see Table 4-13). None of the detections exceeded the MCL of 15 pCi/L (total alpha). Of the two valid detections, one occurred in 1981 and one in 1982. Subsequent samples collected from these two monitoring wells and from all other USGS monitoring wells at RWMC have not shown positive detection of Am-241.

Table 4-13 shows distributions of detections and nondetections of Am-241 in the aquifer between 1972 and 1992; Table 4-14 shows results from 1993 through 2003.

Table 4-13. Americium-241 detections in U.S. Geological Survey aquifer wells from 1972 through 1992.

Americium-241 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1972	1								
	2								
	3				1.5 <sup>b</sup>				
	4	0.040 <sup>c</sup>		5					
1973	1								
	2	0.3	0.13	0.011	0.17				
	3	0.13	0.08	0.14	0.13				
	4								
1974	1			0.027					
	2								
	3								
	4			0.09					
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4								
1977	1								
	2								
	3								
	4								
1978	1								
	2								
	3								
	4								
1979	1								
	2								
	3								
	4								

Table 4-13. (continued).

Americium-241 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1980	1								
	2								
	3								
	4								
1981	1								
	2								
	3								
	4				0.14				
1982	1								
	2								
	3		0.020						
	4								
1983	1								
	2								
	3								
	4								
1984	1								
	2								
	3								
	4								
1985	1								
	2								
	3								
	4								
1986	1								
	2								
	3								
	4								
1987	1								
	2								
	3								
	4								

Table 4-13. (continued).

Americium-241 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1988	1								
	2								
	3								
	4								
1989	1								
	2								
	3								
	4								
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								
1992	1								
	2								
	3								
	4								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L total alpha.									
a. RWMC Production Well.									
b. Barraclough et al. (1976) reported 15±0.04 pCi/L in Table IV and 0.15±0.40 pCi/L in Table A-IX. Microfiche records were unclear.									
c. This concentration value was confirmed with microfiche records; Table A-IX in Barraclough et al. (1976), which reported the value as 0.05±0.01 pCi/L, is incorrect.									
	Analysis was performed for Am-241, but none was detected.								
	Am-241 was detected (pCi/L).								
	Am-241 detections are questionable because of potential cross-contamination (see Section 4.1.6.4).								

Table 4-14. Americium-241 detections in U.S. Geological Survey aquifer wells from 1993 through 2003.

Americium-241 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1993	1								
	2								
	3								
	4								
1994	1								
	2								
	3								
	4								
1995	1								
	2								
	3								
	4								
1996	1								
	2								
	3								
	4								
1997	1								
	2								
	3								
	4								
1998	1								
	2								
	3								
	4								
1999	1								
	2								
	3								
	4								
2000	1								
	2								
	3								
	4								
2001	1								
	2								
	3								
	4								

Table 4-14. (continued).

Americium-241 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
2002	1								
	2								
	3								
	4								
2003	1								
	2								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L total alpha.									
a. RWMC Production Well.									
		Analysis was performed for Am-241, but none was detected.							
		Am-241 was detected (pCi/L).							

#### 4.3.5 Summary of Americium-241

Americium has been detected in surface soil, vegetation, and run-off water, as well as in subsurface core material, soil moisture, aquifer samples, and waste zone probe holes examined with the spectral gamma-logging tool. Table 4-15 provides the concentration ranges, detection frequencies, and exceedances.

Approximately 17% of core samples from the vadose zone collected in the 0 to 35-ft and 35 to 140-ft depth intervals contained detectable amounts of Am-241, compared with 2.6% in the depth interval from 140 to 250 ft. Concentrations of detectable levels of Am-241 in the 0 to 140-ft region of the vadose zone are low and generally range from about 0.01 to 1.0 pCi/L. Most core samples from the 35 to 140-ft depth interval were collected between 30 and 34 m (98 and 113 ft) (i.e., the B-C interbed). Spatially, a cluster of Am-241 detections in core samples appears in the 0 to 35-ft and 35 to 140-ft depth intervals in the region below Pit 5 and at the western end of the SDA near Pits 1 and 2.

The detection frequency for soil moisture in the 0 to 43-m (0 to 140-ft) region is significantly lower (i.e., 4%) than the detection frequency in cores at that same depth interval, possibly indicating that americium is not in a very soluble or readily transportable form. Detections in soil-moisture samples are sporadic and do not exhibit temporal trends.

Since 1975, the detection frequency in the aquifer near RWMC has been 1.3%, which is statistically insignificant because the frequency is similar to the 2.3% detection rate observed in field blank samples.

Numerous Am-241 detections in the upper regions of the vadose zone (particularly in core material), but no statistically significant detections in the deep vadose zone or aquifer, implies that low levels of Am-241 have migrated in upper regions of the RWMC vadose zone but have been captured or filtered in the B-C interbed. This inference is consistent with an interpretation of the adsorptive properties of sediment in the RWMC interbeds conducted by Batcheller and Redden (2004).



Table 4-15. Concentration ranges and detection frequencies of americium-241 in sampled media.

Sample Medium	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Surface soil	20.8	74/356	0	None	0.0049 ± 0.0015	—	1.6 ± 0.2
Surface vegetation	13.0	21/162	0	None	0.0006 ± 0.0002	—	0.11 ± 0.02
Surface run-off	3.8	9/237	0	None	0.066 ± 0.016	—	1.6 ± 0.2
Vadose zone (0 to 35 ft)							
Cores	17.2	5/29	0	None	0.012 ± 0.003	2.24 ± 0.15	9.6 ± 0.7
Soil moisture	2.9	6/155	0	None	0.30 ± 0.09	2.8 ± 0.7	9 ± 2
Vadose zone (35 to 140 ft)							
Cores	17.4	25/144	0	None	0.006 ± 0.002	0.116 ± 0.007	0.908 ± 0.008
Soil moisture	5.1	6/117	0	None	0.8 ± 0.2	4.0 ± 0.9	6.0 ± 1.2
Vadose zone (140 to 250 ft)							
Cores	2.6	4/156	0	None	0.016 ± 0.005	0.023 ± 0.005	0.033 ± 0.003
Soil moisture and perched water	2.3	3/130 <sup>c</sup>	1	IE4	0.041 ± 0.012	10.1 ± 0.8	30 ± 2
Vadose zone (>250 ft)							
Cores	0.0	0/5	0	None	NA	NA	NA
Soil moisture	0.0	0/13	0	None	NA	NA	NA
Aquifer <sup>d</sup>	1.3	11/872	0	None	0.020 ± 0.006	0.50 ± 0.07	1.97 ± 0.13 <sup>d</sup>
Aquifer field blanks	2.3	1/43	0	None	NA	NA	0.031 ± 0.009

Note: Some reported results could be false positives (see caveat in Section 4.3).

a. Ratio = number of detections/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. In addition to the 130 soil-moisture samples, 14 filtered sediment samples from Perched Well USGS-92 also were analyzed, with no detections.

d. Questionable U.S. Geological Survey data from 1972 to 1974 are not included (see Section 4.1.6.4).

## 4.4 Carbon-14

Carbon-14 is a radioisotope generated by nuclear operations as an activation product. It decays by the emission of beta particles and has a 5,715-year half-life. Carbon-14 also occurs naturally with low abundance in the environment.

**CAVEAT:** *Concentrations of C-14 measured in soil-moisture samples may not be representative of actual concentrations in the vadose zone because the process of sampling soil moisture (i.e., vacuum) may cause a significant portion of C-14 to volatilize from the water sample. Therefore, measured concentrations reported in the succeeding sections may be low.*

Since 2001, C-14 in the vapor phase has been evaluated in detail at SVRs 12 and 20. In FY 2004, a study of C-14 throughout the SDA was conducted using samples from Organic Contamination in the Vadose Zone (OCVZ) monitoring ports. To simplify data presentation, C-14 results from core and liquid samples are presented first, followed by vapor results from both the SVR and SDA-wide monitoring, then a summary discusses all the data together.

This section presents results from analyses of core samples, waste zone and vadose zone soil-moisture samples, vapor samples, and the aquifer. No surface soil data are available because C-14 is not a target analyte for surface sampling and analysis. This section summarizes available C-14 monitoring data for all media. The sampling data in this section are evaluated against comparison concentrations in Table 4-1.

### 4.4.1 Waste Zone

Approximately 647 Ci of C-14 was buried in the SDA (through 1999), and an additional 84.6 Ci is projected to be added by 2009, for a total of 731 Ci (see Figure 4-3). Table 4-4 lists waste streams containing the majority of C-14 activity. Gamma spectral logging in the waste zone provides no information about C-14. Most C-14 inventory in the SDA is contained in activated steel. Some of the disposal inventory is in the form of reactor core components, including beryllium reflector blocks and end pieces from reactor cores. Most of the remaining activity is in ion-exchange resin. Typical C-14-bearing waste was buried in SVRs or trenches in the earlier years of operation.

**4.4.1.1 Waste Zone Lysimeter Samples.** Between August 2001 and December 2004, five C-14 analyses were performed on soil-moisture samples collected from five waste zone lysimeters in the SDA, with no positive detections; however, detectable concentrations in 2001 samples could have been hidden by the high detection limits. Because of very small sample volumes, detection sensitivities achieved by the analytical laboratory for these two samples were between 5,000 and 10,000 pCi/L. By contrast, three samples collected from the GEOPS lysimeters in December 2004 produced significantly more volume; hence, detection limits achieved by the laboratory were much lower (i.e., 1.6 to 68 pCi/L).

#### 4.4.2 Vadose Zone

Distributions of C-14 in vadose zone core samples and in samples of soil moisture, perched water, and vapor at various depth intervals are discussed in the following subsections.

**4.4.2.1 Vadose Zone Core Samples.** Between 1994 and 2000, 52 core samples were analyzed for C-14, with no positive detections. Previous core sampling investigations from 1971 to 1993 did not analyze for C-14 because it was not identified as a radionuclide of potential concern until 1994 (Burns et al. 1994; Loehr et al. 1994; Maheras et al. 1994). Also, C-14 was not a targeted radionuclide in the 2003 interbed sediment study. Table 4-20 shows the distribution of samples, concentration ranges, detection frequencies, and exceedances by depth interval.

**4.4.2.2 Lysimeter Samples at Depths from 0 to 35 ft.** Between 1997 and August 2004, 105 analyses for C-14 were performed on soil-moisture samples collected from 16 shallow-depth lysimeters near RWMC, with 10 positive detections. Five of these 10 positive detections came from one lysimeter (i.e., PA02-L16) located next to Pad A. Other samples that contained detectable C-14 were of insufficient volume for confirmation analyses. Lysimeter PA01:L15, also located next to Pad A, does not have a history of positive C-14 detections. Only the August 1997 C-14 result for Lysimeter PA02-L16 was a confirmed positive detection by reanalysis of the original sample.

Carbon-14 was detected at high concentrations in the sample collected from Lysimeter LYS-1:L41 in October 2003. This was the first time enough sample volume was available from this lysimeter to analyze for C-14. The detection and measured concentration are not surprising because the lysimeter is located in the southeastern corner of the SDA near buried beryllium reflector blocks, a waste form associated with C-14. Lysimeter LYS-1:L41 was taken out of service in FY 2004 because it was located in the region affected by grouting of nearby beryllium blocks (Lopez et al. 2005).

Table 4-16 summarizes results for C-14 in shallow vadose zone samples, and Table 4-20 shows the concentration ranges, detection frequencies, and exceedances. Sporadic detections occur, but trends are not apparent.

Table 4-16. Carbon-14 detections in shallow (less than 35 ft) lysimeters since 1997.

Carbon-14 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																		
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	LYS-1: L41	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																	
	2																	
	3							16			11							
	4							19										
1998	1																	
	2																	
	3							22										
	4																	

Table 4-16. (continued).

Carbon-14 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																		
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	LYS-1: L41	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1999	1																	
	2																	
	3		24					26										
	4																	
2000	1																	
	2																	
	3																	
	4	60*																
2001	1																	
	2																	
	3																	
	4																	
2002	1																	
	2																	
	3																	
	4																	
2003	1																	
	2																	
	3																	
	4																	
2004	1																	
	2																	
	3																	
	4																	

Note: The highest result is reported for duplicate samples or reanalysis.

\* = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.

For comparison, the maximum contaminant level = 2,000 pCi/L.

	Analysis was performed, but C-14 was not detected.
	Carbon-14 was detected (pCi/L). Reported concentrations could be biased low (see caveat in Section 4.4).
	Well was removed to accommodate grouting operations.

**4.4.2.3 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1997 and August 2004, 63 analyses for C-14 were performed on soil-moisture samples collected from 13 lysimeters near RWMC, with two positive detections. Table 4-17 summarizes results for C-14 in intermediate-depth vadose zone samples since routine monitoring began in 1997. The positive results did not exceed the MCL of 2,000 pCi/L used for comparison. Table 4-20 shows the concentration ranges, detection frequencies, and exceedances.

Table 4-17. Carbon-14 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Carbon-14 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
1997	1														
	2														
	3														
	4														
1998	1														
	2														
	3														
	4														
1999	1														
	2														
	3														
	4														
2000	1														
	2														
	3														
	4														
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														

Table 4-17. (continued).

Carbon-14 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
2003	1														
	2														
	3														
	4					46									
2004	1														
	2														
	3						39*								
	4														
Note: The highest result is reported for duplicate samples or reanalysis.															
* = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.															
For comparison, the maximum contaminant level = 2,000 pCi/L.															
	Analysis was performed for C-14, but none was detected.														
	Carbon-14 was detected (pCi/L). Reported concentrations could be biased low (see caveat in Section 4.4).														

#### 4.4.2.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.

Ninety-three analyses for C-14 in samples of perched water, filtered sediment, and soil moisture taken near RWMC between 1997 and August 2004 resulted in seven positive detections in soil moisture and four detections in filtered sediment. Soil-moisture samples were obtained from as deep as 141 m (463 ft), but no detections were observed beyond 67 m (220 ft). No water samples exceeded the MCL of 2,000 pCi/L used for comparison. Results for filtered sediment from the samples were all less than soil RBC of 2,845 pCi/g used for comparison (see Table 4-1). Historically, the most frequent detections occurred in Wells PA02 and USGS-92; however, C-14 has not been detected in those wells since 1999 and 2002, respectively.

Perched Water Well D-10 did not yield water from 1996 to May 2004. The May 2004 sample was the first time a sample from Well D-10 was analyzed for C-14. Tritium also was detected in Well D-10; the combination of tritium and C-14 suggests the possibility of irradiated beryllium blocks in the vicinity. Alternatively, some feature of the subsurface could facilitate transport of dual-phase contaminants to this location.

Sporadic detections occur in the deep vadose zone, but no apparent trends are exhibited in the deep lysimeters. Table 4-18 summarizes the results for C-14 in deep vadose zone samples since routine monitoring began in 1997, and Table 4-20 shows the concentration ranges, detection frequencies, and exceedances.

The USGS does not analyze perched water from Well USGS-92 for C-14.

Table 4-18. Carbon-14 detections in deep (greater than 140 ft) lysimeters since 1997.

Carbon-14 Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
1997	1																						
	2																						
	3																						12
	4																						13
1998	1																						
	2																						20
	3																						
	4																						
1999	1																						
	2																						
	3																						
	4																						
2000	1																						
	2																						
	3																						
	4																						
2001	1																						
	2																						
	3																						
	4																						

Table 4-18. (continued).

Carbon-14																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
2002	1																						
	2																						134
	3																						
	4																						
2003	1																						
	2																						
	3																						
	4																						
2004	1																						
	2																						
	3																						
	4																						
Note: The highest result is reported for duplicate samples or reanalysis. * = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly. For comparison, the maximum contaminant level = 2,000 pCi/L.																							
	Analysis was performed for C-14, but none was detected.																						
	Carbon-14 was detected (nCi/L). Reported concentrations could be biased low (see caveat in Section 4.4).																						



#### **4.4.3 Soil-Gas Monitoring near Soil Vault Rows 12 and 20 and Vapor Monitoring in the Subsurface Disposal Area Vadose Zone**

Studies of C-14 and tritium in soil gas are ongoing in SVRs 12 and 20. Soil Vault Row 20 contains beryllium reflector blocks from the Advanced Test Reactor, which contained approximately 12 Ci of C-14 at the time of disposal. Routine<sup>a</sup> soil-gas sampling for C-14 began at SVR 20 during December 2001. During FY 2004, an early action to locate and grout beryllium buried in the SDA was deployed (Lopez et al. 2005). Soil-gas sampling for C-14 was discontinued at SVR 20 after March 2004 because grouting operations required removal of the vapor sampling ports in early summer 2004. Two new wells (i.e., RWMC 2022 and RWMC 2023; aliases are SVR 20-1 and SVR 20-2) with vapor ports were installed at SVR 20 in August and November 2004 to sample soil gas near grouted beryllium. Although data from these wells are not directly comparable to the 1995 to 2003 data set, the new wells are close enough to collect data for assessing the effects of grouting on the beryllium blocks. After about 1 year of monitoring at these new locations, C-14 activity is still elevated and similar to pregrouting levels near the beryllium blocks (i.e., SVR 20). Further discussion, including data, is available in Section 3.9.

Soil Vault Row 12, also in the southeastern corner of the SDA, is known to contain large amounts of C-14 because of numerous disposals of activated stainless steel. These disposals are probably highly irradiated stainless steel end pieces removed from Experimental Breeder Reactor II spent fuel elements (Salomon 2003). Spent fuel elements from Experimental Breeder Reactor II were sent to the Idaho Nuclear Technology and Engineering Center (INTEC) for processing after use. The stainless steel end pieces were physically separated from fuel in underwater basins at the Chemical Processing Plant (now INTEC), CPP-603, then buried in unsealed baskets at the SDA. Ten shipments were sent from CPP-603 and placed in SVR 12. The rate of C-14 release from activated steel, presumably by corrosion, is being studied at SVR 12. Nine Type B probes with vapor ports were installed at SVR 12 in 2001, and the initial sampling was conducted in 2002. Samples have been collected from all of the ports since 2002 until early summer 2004, when all but three of these probes (i.e., SVR 12-3-VP1, SVR 12-3-VP-2, and SVR 12-3-VP-3) were removed from SVR 12 to facilitate grouting operations. Sampling for C-14 from the remaining ports resumed in September 2004.

**4.4.3.1 Vapor Results from Soil Vault Rows 12 and 20.** Samples have been collected quarterly from functioning vapor ports at SVRs 12 and 20 since 2001, except for the period when beryllium grouting operations precluded routine sampling. Figure 4-48 shows sampling sites near SVRs 12 and 20. Samples are analyzed for C-14 or C-14-specific activity (i.e., C-14 activity per unit mass of total carbon). Table 4-20 shows C-14 concentration ranges, detection frequencies, and exceedances from December 2001 to November 2004 for functioning probes at SVR 12. Results for C-14 analyses indicate that the C-14-specific activity in SVR 12 samples is two to three orders of magnitude greater than the typical background concentration of C-14 (i.e., 6.5 pCi/g of carbon). The concentration of tritium in soil gas near SVR 12 also was measured and was determined to be near background levels. The absence of tritium in the soil gas provides confidence that the C-14 detected in this location originates from the activated stainless steel in SVR 12 rather than activated beryllium.

Specific activity of C-14 in carbon dioxide has been measured in grab samples of soil gas collected between June 1996 to March 2004 from GSP-1 ports located near SVR 20. Table 4-20 summarizes the results for soil-gas samples. These results are for samples collected using caustic solutions in bubblers before FY 2000 and in Tedlar bags after FY 2000. The SVR 20-IPV-5-VP3 soil-gas sampling port was located approximately 5 m (16 ft) from the beryllium waste, and the GSP-1 gas sampling ports were located approximately 0.8 to 1 m (2.6 to 3 ft) from the waste. The specific activity of C-14 in carbon

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a. Soil-gas measurements of C-14 at SVR 20 during 1996 and 1997 were collected under a focused study and were not part of routine monitoring.

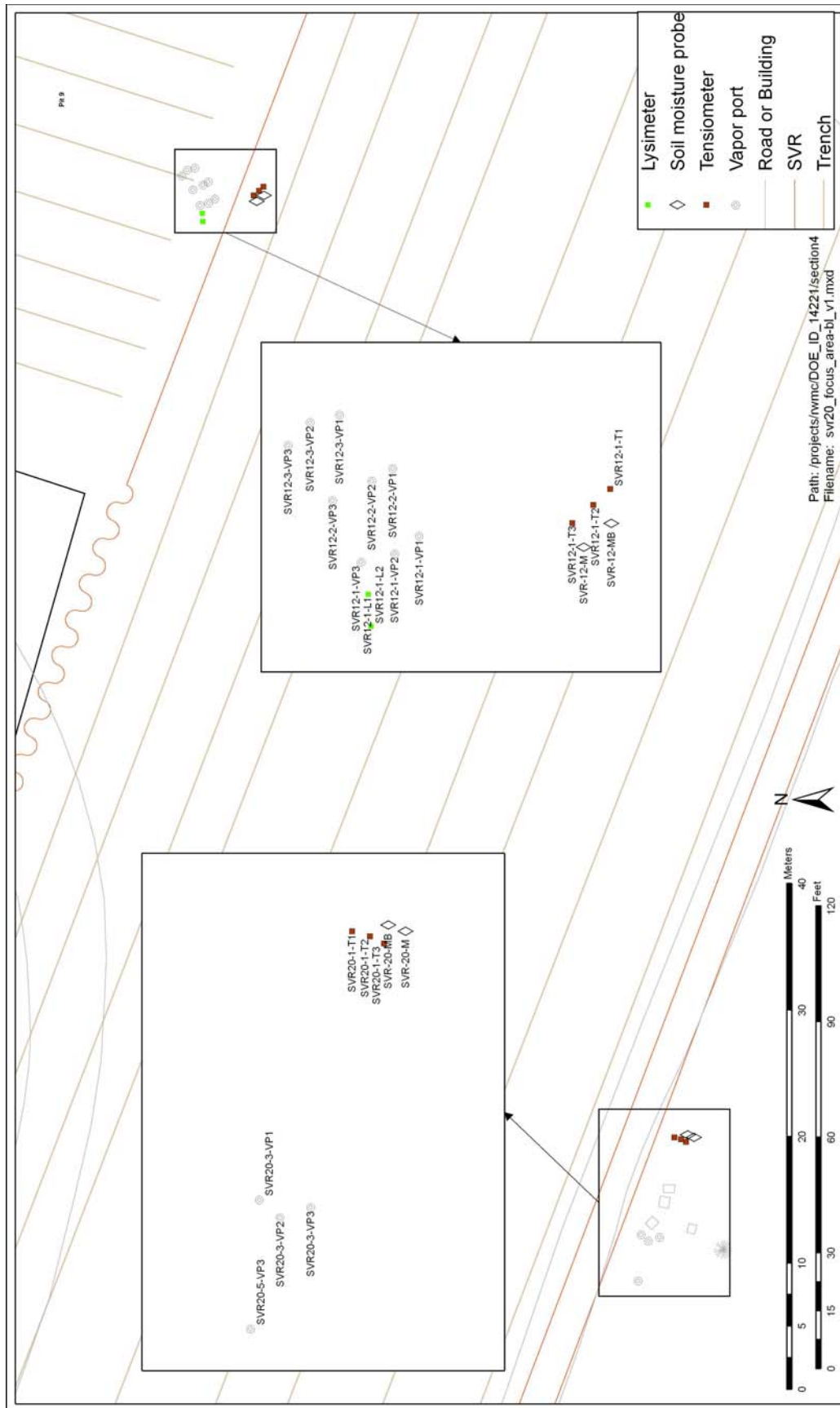


Figure 4-48. Waste zone monitoring near or in Soil Vault Rows 12 and 20.

dioxide is an approximate factor of three less at the more distant location, based on samples from both ports taken November 15, 2001, and August 23, 2002. Postgrouting C-14 results do not show a measurable decrease in activity near the grouted beryllium blocks, which may be from residual quantities of C-14 released in the area before grouting. More discussion about postgrout monitoring is provided in Sections 4.4.4 and 3.1.6.

**4.4.3.2 Distribution of Volatile Carbon-14 in the Subsurface Disposal Area Vadose Zone.** Distribution of volatile C-14 in the vadose zone at RWMC was examined in FY 2004. Vapor samples were collected from OCVZ monitoring ports at depths from 11 to 51 m (35 to 166 ft) to evaluate vapor-phase transport of C-14 in the vadose zone. Figure 4-49 shows C-14 sample locations. Table 4-20 provides the concentration ranges and detection frequencies of C-14 vapor at various depth intervals in the vadose zone. Samples were collected from the intermediate vadose zone to evaluate downward migration of C-14 near known beryllium block disposal locations.

Table 4-20 reports vapor results in units of C-14 activity per unit volume of gas collected. Carbon-14 vapor concentrations were compared to soil-moisture data from lysimeter wells near the vapor ports. Carbon-14 was detected above background (0.3 pCi/L) in all vapor samples but was not detected in any soil-moisture samples; consequently, numerical correlations between vapor and water results cannot be made for these samples.

Carbon-14 vapor samples were collected at 10 locations around the SDA and were detected at concentrations slightly above the background level of 0.3 pCi/L in seven of the 10 gas sampling wells. Carbon-14 was not detected at any depths below approximately 53 m (175 ft) (see Figure 4-50). The highest concentration was detected in Well 3V at 14 m (47 ft) deep.

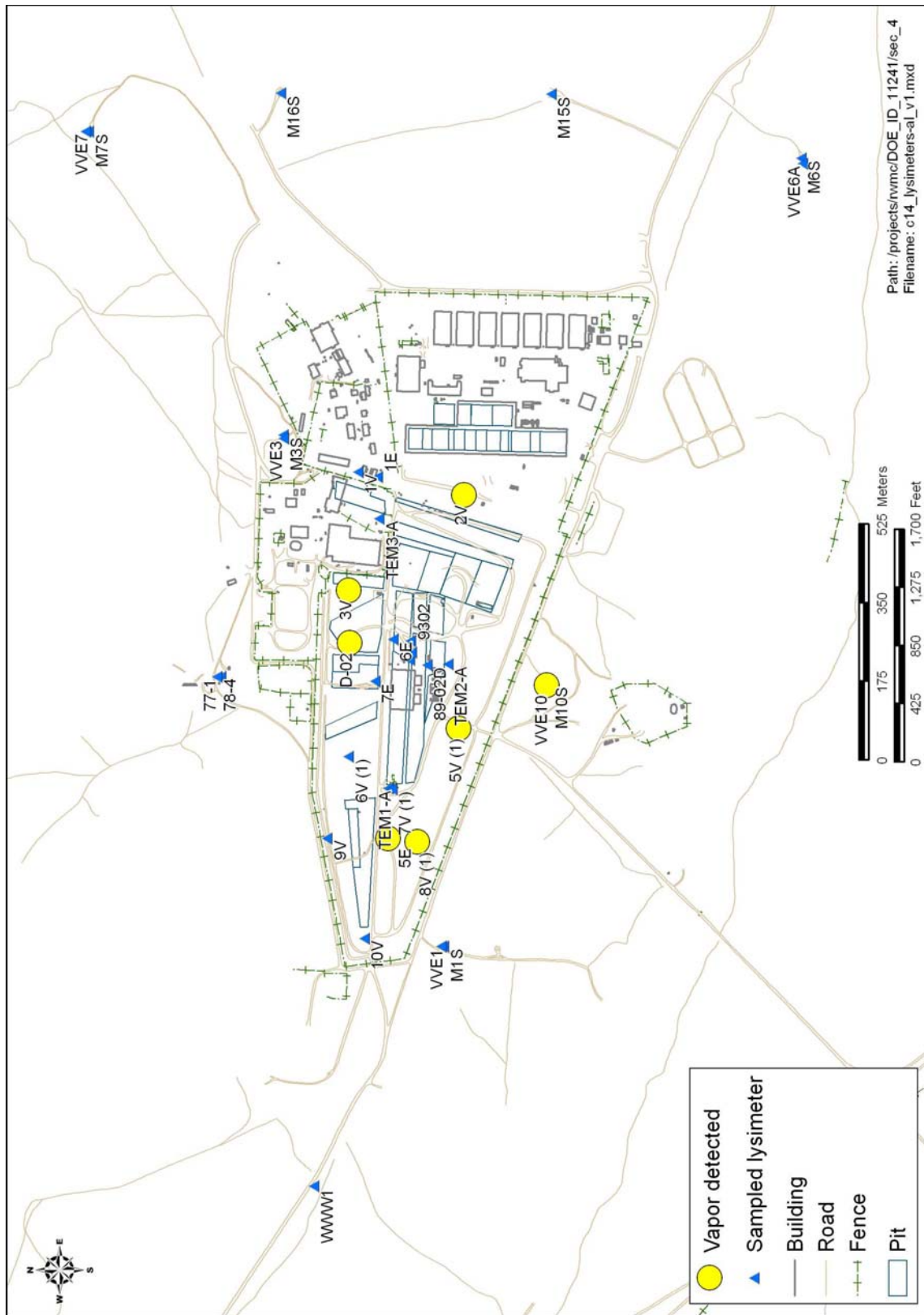


Figure 4-49. Carbon-14 detections in vapor ports.

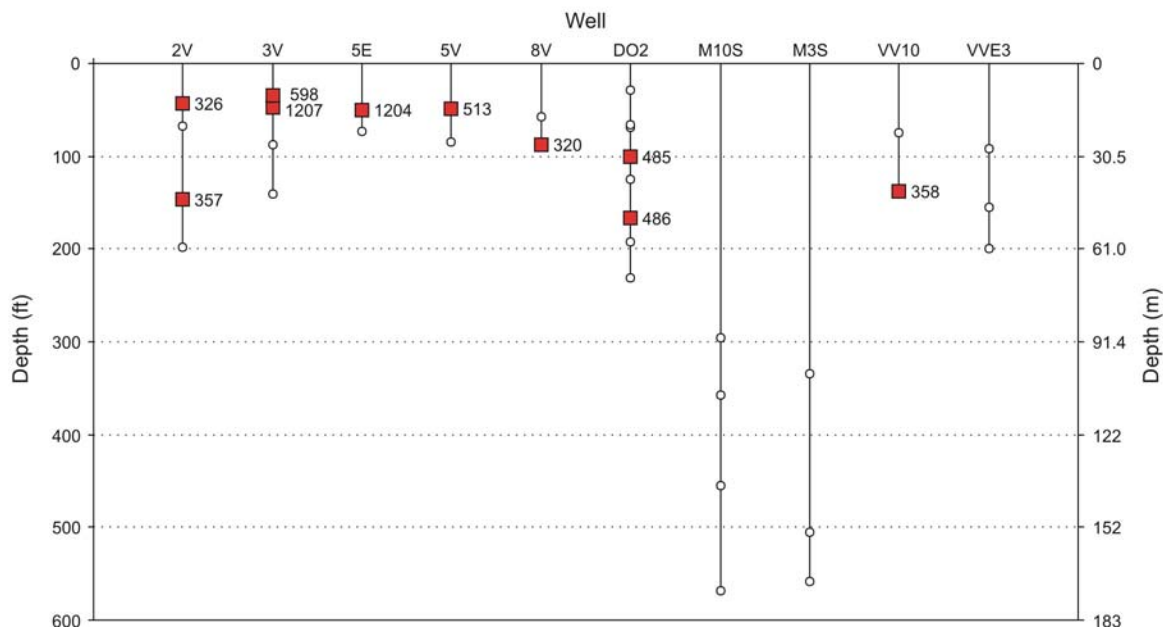


Figure 4-50. Carbon-14 gas sampling wells and detections (pCi/L) (red squares).

#### 4.4.4 Aquifer

Of the 435 analyses for C-14 performed on aquifer samples collected from 16 monitoring wells near RWMC between 1994 and August 2004, 28 were positive detections. Table 4-19 shows the distribution of detected concentrations of C-14 over the entire span of C-14 aquifer monitoring. Table 4-20 shows the concentration ranges, detection frequencies, and exceedances. Results for samples from the aquifer near RWMC show sporadic detections but no evident trends. None of the positive detections exceeded the MCL of 2,000 pCi/L. Concentrations of C-14 are two to three orders of magnitude less than the MCL.

Monitoring Wells M12S and M13S, located 1.6 to 3.2 km (1 to 2 mi) upgradient from RWMC, exhibit the most frequent C-14 detections. Carbon-14 may be migrating from the SDA in a vapor phase or originating from INTEC or Reactor Technology Complex (RTC) (formerly Test Reactor Area). A possible source of C-14 at these well locations is difficult to determine because neither well contains distinctive signature analytes (e.g., chromium, chlorides, sulfates, Tc-99, or I-129) that implicate upgradient facilities or the SDA. If upgradient influences were responsible for the C-14, tritium also would be expected, as it is present in most groundwater monitoring wells at RTC and INTEC; however, tritium is detected in Well M12S but not in Well M13S.

Data collected in September 1996 suggest seven other positive C-14 results that are not included in this analysis because of unacceptable data quality. These seven results were reevaluated and classified as either false positive or estimated results because C-14 also was detected in the corresponding field blank at a concentration equivalent to those in the sample results. The September 1996 data were revalidated, and a revised limitations and validations report was issued.

The USGS does not analyze for C-14 in the eight wells that they manage, control, and routinely sample.

Table 4-19. Carbon-14 detections in aquifer wells since 1994.

Carbon-14 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	Alla 31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS- 127
1994	1																
	2																
	3												5.7				
	4																
1995	1												28				
	2																
	3																
	4																
1996	1																
	2																
	3																
	4																
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4				3.0	6.7											
1999	1																
	2				4.4						4.9						
	3																
	4						11										
2000	1													5.3	1.8		
	2																
	3																
	4				2.1	3.2	4.0				2.8	3.3			2.2		
2001	1																
	2																
	3			2.8	2.9	3.3											4.5
	4									42							
2002	1																
	2							4.5		7.5							
	3	3.1															
	4	7.1											3.5				

Table 4-19. (continued).

Table 7-134 (continued).

Carbon-14 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	Alla 31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 2,000 pCi/L.																	
	Analysis was performed, but C-14 was not detected.																
	Carbon-14 was detected (pCi/L).																
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.																

#### 4.4.5 Summary of Carbon-14

Carbon-14 has been detected in about 10% of the vadose zone soil-moisture samples (see Table 4-20); however, detections are infrequent, most concentrations are low, and trends are not discernible at any location. Historically, the most frequent C-14 detections occurred in samples from the PA02:L16 shallow lysimeter and from the USGS-092 perched water well. Although C-14 has not been detected in Well USGS-092 since 2002 or in Well PA02 since 1999, repeated positive detections in Well USGS-92 between 1997 and 2002 suggest that C-14 has migrated to the 67-m (220-ft) perched water region beneath RWMC (Holdren et al. 2002, Section 4). Because of the volatile nature of C-14, samples obtained by suction lysimeters (vacuum) may not be representative of the concentration in the vadose zone (i.e., if C-14 is volatilized during sample collection, the sample could yield either a nondetection or a biased low concentration). Vapor samples collected from the vadose zone indicate that low concentrations of C-14 are present in the vapor phase.

Higher concentrations of C-14 were observed in the soil-moisture sample from Lysimeter LYS-1:L41; however, elevated concentrations are expected at this location because the lysimeter is located near buried reactor beryllium reflector blocks, which have released C-14 and tritium into the surrounding area. Lysimeter LYS-1:L41 was taken out of service in FY 2004 because it was located in the region affected by beryllium block grouting during July and August 2004.

The most frequent aquifer detections occur in aquifer Wells M12S and M13S, which are hydrologically upgradient from RWMC. The upgradient detections of C-14 are not yet understood but may be caused by vapor transport from the SDA or unidentified upgradient sources or could be false positive detections. Of the aquifer samples collected and analyzed for C-14, 6% have positive detections; however, the detection frequency of C-14 in field blanks is also about 6% (see Table 4-20), indicating that the aquifer detections may be false positives.

Table 4-20. Concentration ranges and detection frequencies of carbon-14 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations			Units
					Minimum	Mean	Maximum	
Vadose zone (0 to 35 ft)								
Cores	0.0	0/11	0	None	NA	NA	NA	pCi/g
Soil moisture	9.5	10/105	1	LVS-1:L41	11 ± 3	463 ± 17	4350 ± 116	pCi/L
Vapor	0.0	0/2	0	None	NA	NA	NA	pCi/L
Soil gas (SVR 12)	92.8	65/70	65 <sup>c</sup>	VP1, VP2, VP3	110 <sup>d</sup>	1,648 <sup>d</sup>	16,000 <sup>d</sup>	pCi/g
Soil gas (SVR 20)	100	31/31	31 <sup>c</sup>	GSP-1, IPV-5-VP3	12,000 <sup>d</sup>	91,968 <sup>d</sup>	360,000 <sup>d</sup>	pCi/g
Vadose zone (35 to 140 ft)								
Cores	0.0	0/25	0	None	NA	NA	NA	pCi/g
Soil moisture	3.2	2/63	0	None	39 ± 10 <sup>e</sup>	43 ± 12	46 ± 14	pCi/L
Vapor	42.1	8/19	0	None	0.32	0.63	1.21	pCi/L
Vadose zone (140 to 250 ft)								
Cores	0.0	0/16	0	None	NA	NA	NA	pCi/g
Soil moisture and perched water	10.0	7/70 <sup>f</sup>	0	None	12 ± 3	57 ± 10	185 ± 16 <sup>e</sup>	pCi/L
Vapor	28.6	2/7	0	None	0.357	0.422	0.486	pCi/L
Vadose zone (>250 ft)								
Cores	NA	NA	NA	NA	NA	NA	NA	pCi/g
Soil moisture	0.0	0/13	0	None	NA	NA	NA	pCi/L
Vapor	0.0	0/7	0	None	NA	NA	NA	pCi/L
Aquifer	6.4	28/435	0	None	1.8 ± 0.5	6.4 ± 0.9	42 ± 5	pCi/L
Aquifer field blanks	5.7	2/35	0	None	2.0 ± 0.5	19 ± 3	36 ± 6	pCi/L
<sup>a</sup> . Ratio = number of detections above background concentrations/number of sample analyses.								
<sup>b</sup> . Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.								
<sup>c</sup> . Vapor results are compared to a C-14 background concentration of 6.5 pCi/g of carbon. Carbon is calculated from the amount of carbon dioxide in the sample.								
<sup>d</sup> . Relative uncertainties are typically 5 to 10%. In addition, the carbon dioxide concentrations in these samples are relatively low.								
<sup>e</sup> . Concentrations with a J subscript denote that J data validation qualifier flags were assigned because of analytical quality control anomalies. Results should be used only as estimated quantities.								
<sup>f</sup> . In addition to the 70 soil-moisture samples, 10 filtered sediment samples from Perched Well USGS-92 also were analyzed, with four detections at concentrations to 3 pCi/g.								

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. Vapor results are compared to a C-14 background concentration of 6.5 pCi/g of carbon. Carbon is calculated from the amount of carbon dioxide in the sample.

d. Relative uncertainties are typically 5 to 10%. In addition, the carbon dioxide concentrations in these samples are relatively low.

e. Concentrations with a J subscript denote that J data validation qualifier flags were assigned because of analytical quality control anomalies. Results should be used only as estimated quantities.

f. In addition to the 70 soil-moisture samples, 10 filtered sediment samples from Perched Well USGS-92 also were analyzed, with four detections at concentrations to 3 pCi/g.



## 4.5 Cesium-137

Cesium-137 is a fission product generated primarily by nuclear reactor operations and weapons testing. It decays by the emission of beta particles and gamma rays, has a 30-year half-life, and is ubiquitous globally in the environment at low levels because of historical atmospheric nuclear bomb testing.

Cesium-137 is rarely detected in samples from vadose zone cores, lysimeters, perched water, and aquifer wells. This section summarizes Cs-137 monitoring data for all media. Sampling data in this section are evaluated against comparison concentrations in Table 4-1. Table 4-21 provides Cs-137 detections and nondetections in INL Site and USGS aquifer monitoring wells from 1972 through 2005.

### 4.5.1 Waste Zone

Approximately  $1.72\text{E}+05$  Ci of Cs-137 was buried in the SDA (through 1999), and an additional  $3.04\text{E}+02$  Ci is projected to be added by 2009, for a total of  $1.73\text{E}+05$  Ci. Table 4-4 identifies waste streams containing the majority of Cs-137 activity. The primary source of Cs-137 in the SDA is INL Site reactor operations waste and subassembly hardware. Figure 4-5 shows Cs-137 densities in the SDA.

**4.5.1.1 Waste Zone Spectral Logging.** The gamma spectral logging tool detected Cs-137 based on the 662-keV gamma rays. Of the 135 probeholes logged using this tool, 43 (32%) showed the presence of Cs-137 above the noise level. Of the 4,863 total measurements collected from all probes at all depths, 359 (7%) showed the presence of Cs-137 above the noise level. The Cs-137 detection limit was approximately 0.3 pCi/g. Maximum and average observed Cs-137 levels were 141 and 5.3 pCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Cs-137 is uniformly distributed near the measurement points.

**4.5.1.2 Waste Zone Lysimeter Samples.** Between August 2001 and December 2004, 16 Cs-137 analyses were performed on soil-moisture samples collected from 11 waste zone lysimeters in the SDA, yielding one positive detection. This detection occurred in a sample obtained from the Americium/Neptunium Focus Area in September 2003; the concentration was  $473 \pm 50$  pCi/L.

### 4.5.2 Surface

Between 1994 and 2004, 356 soil samples taken near RWMC were analyzed for Cs-137, yielding 216 positive detections. Detections ranged from  $(3.3 \pm 1.0)\text{E}-02$  pCi/g at sampling location RW 5 to  $1.26 \pm 0.10$  pCi/g at RW 4-4. Twenty detections exceeded the surficial soil background upper tolerance limit of 0.82 pCi/g, but none exceeded the  $1\text{E}+05$  RBC of 183 pCi/g.

Between 1990 and 2004, 162 vegetation samples from RWMC were analyzed for Cs-137, yielding two positive detections. Positive results ranged from  $(1.0 \pm 0.3)\text{E}-01$  pCi/g at sampling location RW 3 to  $(2.2 \pm 0.6)\text{E}-01$  pCi/g at RW 1.

Between 1991 and 2004, 237 samples of surface run-off water from RWMC were analyzed for Cs-137, yielding 12 positive detections. Positive results ranged from  $0.72 \pm 0.19$  pCi/L at location TSA-1 to  $37 \pm 3$  pCi/L at the SDA. All concentrations were less than the MCL of 200 pCi/L.

### 4.5.3 Vadose Zone

The following subsections discuss distribution of Tc-99 in vadose zone cores, soil moisture, and perched water in the various depth intervals.

#### **4.5.3.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.**

Three samples were analyzed for gamma-emitting radionuclides, and Cs-137 was detected in one sample at a concentration of  $0.040 \pm 0.009$  pCi/g. This concentration is typical of fallout levels found in surface soil around the INL Site (see comparison Table 4-1).

**4.5.3.2 Vadose Zone Core Samples.** Between 1971 and 2000, 345 vadose zone core samples were analyzed for Cs-137, yielding 13 positive detections (see Table 4-22). Seven of the 13 detections (1971 to 1972) were associated with cross-contamination in the core sampling method (see Section 4.1.6.4) (Barraclough et al. 1976; DOE-ID 1983). Concentrations of detected Cs-137 varied from  $0.040 \pm 0.010$  to  $0.55 \pm 0.04$  pCi/g; these are typical of surface soil background concentrations, below the upper background tolerance limit of 0.82 pCi/g, and below the 1E+05 RBC of 183 pCi/g (see comparison Table 4-1). Table 4-22 presents the summary of concentration ranges, detection rates, and exceedances since 1971.

**4.5.3.3 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1997 and August 2004, 164 analyses for Cs-137 were performed on soil-moisture samples collected from 18 shallow-depth lysimeters near RWMC, yielding two positive detections (see Table 4-22). Detected concentrations, ranging from 324 to 1,760 pCi/L, exceed the MCL of 200 pCi/L used for comparison. Samples were obtained from Lysimeter PA01:L15 in April 1996 and from Lysimeter 98-1:L35 in September 2000. No other detections of Cs-137 have occurred in any lysimeters or perched water wells from this depth range since sample collection began in 1997. Therefore, a table showing historical detections and nondetections in the shallow vadose zone is not presented. Table 4-22 presents the summary of concentration ranges, detection rates, and exceedances since 1997.

**4.5.3.4 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1997 and August 2004, 133 analyses for Cs-137 were performed on soil-moisture samples collected from 14 intermediate-depth lysimeters near RWMC, yielding no positive detections (see Table 4-22). No Cs-137 has been detected in any lysimeters or perched water wells from this depth range since sample collection began in 1997. Therefore, a table showing historical detections and nondetections in the intermediate-depth vadose zone is not presented. Table 4-22 presents the summary of concentration ranges, detection rates, and exceedances since 1997.

**4.5.3.5 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Including USGS analyses, 152 analyses for Cs-137 were performed on samples collected from 19 lysimeters and four perched water wells near RWMC between 1972 and August 2004, yielding one positive detection (see Table 4-22). The detected concentration of  $105 \pm 12$  pCi/L was less than the MCL of 200 pCi/L used for comparison. No other detections of Cs-137 have occurred in lysimeters or perched water wells from this depth range since sample collection began in 1972. Therefore, a table showing historical detections and nondetections in the deep vadose zone is not presented. Table 4-22 presents the summary of concentration ranges, detection rates, and exceedances since 1972.

Table 4-21. Cesium-137 detections and nondetections in Idaho National Laboratory and U.S. Geological Survey aquifer monitoring wells from 1972 through 2005.

Cesium-137																								
Radioactive Waste Management Complex Idaho National Laboratory and U.S. Geological Survey Aquifer Monitoring Wells																								
Year	FY Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS- 117	USGS- 119	USGS- 120	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2
1972	2,4			90	30																			
1973	1 to 4		24	27	90																			
1974	1 to 4	90																						
1975	1 to 4																							
1976	2																							
1977	1,3			24																				
1978	3																							
1979	1,3																							
1980	1,3																							
1981	1,3																							
1982	1,3																							
1983	1,2,3																							
1984	1,3																							
1985	1,3																							
1986	1,3																							
1987	1,3,4		30	25																				
1988	1,3,4																							
1989	1 to 4																							
1990	1 to 4																							
1991	1,3																							
1992	1,2,3																							
1993																								
1994	1 to 4																							
1995	1 to 4	1020																						
1996	1																							
	2																							
	3											20												
	4																							
1997	1																							
	2																							
	3																							
	4																							
1998	1																							
	2																							
	3																							
	4																							

Table 4-21. (continued).

Cesium-137																								
Radioactive Waste Management Complex Idaho National Laboratory and U.S. Geological Survey Aquifer Monitoring Wells																								
Year	FY Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS- 117	USGS- 119	USGS- 120	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2
1999	1																							
	2																							
	3																							
	4																							
2000	1																							
	2																							
	3																							
	4																							
2001	1																7.8	7.6						
	2																							
	3																							
	4																							
2002	1																							
	2																							
	3													3.9										
	4																							
2003	1																							
	2																							
	3																							
	4																							
2004	1																							
	2																							
	3																							
	4																							
2005	1																							
	2																							
	3																							
Note: If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.																								
Analysis was performed for Cs-137, but none detected.																								
Cs-137 detected (pCi/L).																								
Out of service.																								

Table 4-22. Detection frequencies for cesium-137 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Surface soil	60.6	216/356	0	None	0.033 ± 0.010	NA	1.26 ± 0.10 pCi/g
Surface vegetation	1.2	2/162	0	None	0.10 ± 0.03	NA	0.22 ± 0.06 pCi/g
Surface run-off	5.1	12/237	0	None	0.72 ± 0.19	NA	37 ± 3 pCi/L
Vadose zone (0 to 35 ft)							
Cores	9.4	3/32	0	None	0.09 ± 0.02	0.19 ± 0.03	0.37 ± 0.04 pCi/g
Soil moisture	1.2	2/164	0	None	324 ± 24	1042 ± 80	1760 ± 136 pCi/L
Vadose zone (35 to 140 ft)							
Cores	4.2	5/119	0	None	0.08 ± 0.02	0.21 ± 0.02	0.55 ± 0.04 pCi/g
Soil moisture	0.0	0/133	0	None	NA	NA	NA pCi/L
Vadose zone (140 to 250 ft)							
Cores	3.1	4/131	0	None	0.04 ± 0.01	0.12 ± 0.02	0.23 ± 0.03 pCi/g
Soil moisture and perched water	0.7	1/39	0	None	NA	NA	105 ± 12 pCi/L
Vadose zone (>250 ft)							
Cores	11.1 <sup>c</sup>	1/9	0	None	NA	NA	0.18 ± 0.03 pCi/g
Soil moisture	0.0	0/13	0	None	NA	NA	NA pCi/L
Aquifer	1.5	14/920	1	USGS-87	3.9 ± 0.8	106 ± 8	1020 ± 30 pCi/L
Aquifer field blanks	0.0	0/21	0	None	NA	NA	NA pCi/L

a. Ratio = number of detections above upper background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. Detection frequency at this depth interval is misleading because the sample set is too small (nine samples) to provide any statistical significance or meaning. Also, the one detection at this depth is the questionable 1971 and 1972 U.S. Geological Survey core data (see Section 4.1.6.4).

#### **4.5.4 Aquifer**

Between 1996 and May 2004, 404 analyses for Cs-137 were performed on INL Site aquifer well samples from 16 monitoring wells near RWMC, yielding four positive detections (see Table 4-21). Detections were one-time occurrences in Wells M4D, M7S, M12S, and M13S, with concentrations ranging from 3.9 to 20 pCi/L. No detections exceeded the MCL of 200 pCi/L. Because only four detections were made, the data are presented with USGS data in a single table (see Table 4-21). Table 4-22 summarizes concentration ranges, detection rates, and exceedances since 1996.

Between 1972 and May 2004, the USGS performed 516 Cs-137 analyses on aquifer well samples collected from eight USGS monitoring wells near RWMC, yielding 10 positive detections. Concentrations ranged from 24 to 1,020 pCi/L; one detection in 1995 exceeded the drinking water MCL of 200 pCi/L. That detection (i.e., 1,020 pCi/L) occurred in Well USGS-87, and no other Cs-137 detections have occurred in subsequent sampling events. Six of the 10 detections occurred between 1972 and 1974, shortly after the wells were drilled and installed. This period is associated with cross-contamination in core drilling and sampling methods (see Section 4.1.6.4) (Barraclough et al. 1976; DOE-ID 1983). Cesium-137 has not been detected in USGS aquifer monitoring wells at RWMC for more than 10 years. Table 4-22 summarizes concentration ranges, detection rates, and exceedances since 1972.

#### **4.5.5 Summary of Cesium-137**

Cesium-137 was not detected above background in core samples, was seldom detected in vadose zone soil moisture, and was infrequently detected in aquifer samples. Table 4-22 shows detection rates, concentration ranges, and exceedances from 1971 through 2005.

## 4.6 Chlorine-36

Chlorine-36 is a radioisotope generated by nuclear reactor operations and weapons testing. In addition, cosmic rays interact with argon to produce extremely low concentrations of chlorine-36 in the environment. It decays by the emission of beta particles and has a half-life of  $3.01 \times 10^5$  years.

This section summarizes available Cl-36 monitoring data for all sample media. No waste zone lysimeter data are available because Cl-36 is not a targeted analyte in waste zone monitoring; other radionuclides have analytical priority. No surface soil data are available because Cl-36 has not been a target analyte for surface soil, vegetation, and run-off water monitoring. Core samples were not analyzed for Cl-36 because it had not been identified as a contaminant of potential concern at the time of the core sampling campaigns. Sampling data in this section are evaluated against the comparison concentrations shown in Table 4-1.

### 4.6.1 Waste Zone

Approximately 1.12 Ci of Cl-36 was buried in the SDA (through 1999), and an additional 0.538 Ci is projected to be added by 2009, for a total of 1.66 Ci (see Figure 4-4). Table 4-4 identifies waste streams containing the majority of Cl-36 activity. Gamma spectral logging data provide no information about Cl-36.

### 4.6.2 Vadose Zone

The distribution of Cl-36 in vadose zone soil moisture and perched water is discussed in the following subsections. Routine Cl-36 monitoring in the vadose zone did not begin until October 2002.

**4.6.2.1 Lysimeter Samples at Depths of 0 to 35 ft.** Between 2002 and August 2004, 43 analyses for Cl-36 on soil-moisture samples collected from 11 shallow-depth lysimeters near RWMC resulted in four positive detections. The detections are considerably less than the MCL of 700 pCi/L used for comparison. Table 4-23 summarizes Cl-36 detections in shallow-depth lysimeters; Table 4-27 shows the concentration ranges and detection frequencies. Chlorine-36 was not previously detected from Lysimeter PA01:L15 before August 2004, nor have any detections been associated with subsequent sampling of Lysimeters 98-5:L38, W08:L13, and W23:L07. Sporadic detections occur, but no apparent trends are exhibited in the shallow-depth lysimeters.

**4.6.2.2 Lysimeter Samples at Depths of 35 to 140 ft.** Between 2002 and August 2004, 67 analyses for Cl-36 were performed on soil-moisture samples collected from 13 intermediate-depth lysimeters near RWMC, with three positive detections. The detections are considerably less than the MCL of 700 pCi/L used for comparison. Table 4-24 summarizes Cl-36 detections in intermediate-depth lysimeters since 2002, and Table 4-27 shows the concentration ranges and detection frequencies. Sporadic detections occur, but no apparent trends are exhibited in the intermediate depth.

**4.6.2.3 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between 2002 and August 2004, 49 analyses for Cl-36 were performed on samples collected from 15 lysimeters and three perched water wells near RWMC, yielding one positive detection. The detection occurred in perched water Well USGS-92, and the concentration is considerably below the MCL of 700 pCi/L used for comparison. This is the first time Cl-36 was detected in USGS-92, and subsequent sampling has yielded no detections. Table 4-25 summarizes the occurrence of Cl-36 detections in since 2002, and Table 4-27 shows the concentration ranges and detection frequencies.

Table 4-23. Chlorine-36 detections in shallow-depth (less than 35 ft) lysimeters since 2003.

Chlorine-36 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
2002	1 to 4																
2003	1			3.5							5.8			32*			
	2																
	3																
	4																
2004	1																
	2																
	3																
	4					16*											
Note: The highest result is reported for duplicate samples or reanalysis. * = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly. For comparison, the maximum contaminant level = 700 pCi/L.																	
		Analysis was performed, but Cl-36 was not detected.															
		Cl-36 was detected (pCi/L.)															

Table 4-24. Chlorine-36 detections in intermediate-depth (35 to 140 ft) lysimeters since 2003.

Chlorine-36 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
2002	1 to 4														
2003	1				5.6										
	2														
	3														
	4														
2004	1														
	2														
	3		28		32										
	4														
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 700 pCi/L.															
		Analysis was performed for Cl-36, but none was detected.													
		Cl-36 was detected (pCi/L.).													



Table 4-25. Chlorine-36 detections in deep (greater than 140 ft) lysimeters and perched water wells since 2003.

Chlorine-36																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
2002	1 to 4																						
2003	1																						8.7
	2																						
	3																						
	4																						
2004	1																						
	2																						
	3																						
	4																						
Note: The highest result is reported for duplicate samples or reanalysis.																							
For comparison, the maximum contaminant level = 700 pCi/L.																							
	Analysis was performed for Cl-36, but none was detected.																						
	Cl-36 was detected (pCi/L).																						

### 4.6.3 Aquifer

Aquifer monitoring for Cl-36 began in 2001, and analytical priority and schedule for routine monitoring were established in 2003. Between 2001 and August 2004, 78 analyses for Cl-36 were performed on aquifer samples collected from 15 monitoring wells near RWMC, yielding no positive detections. Table 4-26 summarizes the Cl-36 occurrences in aquifer samples, and Table 4-27 provides concentration ranges and detection frequencies in sampled media. At the end of 2004, the frequency of monitoring the aquifer near RWMC was changed to biannually, thus only data from the first three quarters of FY 2004 are available (see Table 4-26). No samples from the aquifer near RWMC were analyzed for Cl-36 in FY 2003.

The USGS does not analyze for Cl-36 in the eight wells that they manage, control, and routinely sample.

Table 4-26. Chlorine-36 detections in aquifer wells since 2001.

Chlorine-36 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	All A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 700 pCi/L.																	
		Analysis was performed, but Cl-36 was not detected.															
		Cl-36 was detected (pCi/L).															
		Well is out of service. Well was rendered inoperable after repairs were unsuccessful.															

#### **4.6.4 Summary of Chlorine-36**

Analytical data to evaluate the nature and extent of Cl-36 contamination at RWMC are limited because analysis for Cl-36 was not routine until 2001. Also, the analytical priority and the schedule for sampling and analysis for Cl-36 were not officially established until the end of FY 2003. Therefore, minimal data existed before then. Locations of Cl-36 detections in the vadose zone are the same locations where uranium isotopes and Tc-99 have been detected. Historically, Cl-36 detections are rare and have been confined to the vadose zone between 3 and 31 m (10 and 101 ft). Also, detection frequencies are highest in shallow regions of the vadose zone and lowest in deep regions (see Table 4-27). All positive results are less than the MCL of 700 pCi/L.

Table 4-27. Concentration ranges and detection frequencies of chlorine-36 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations			Units
					Minimum	Mean	Maximum	
Vadose zone (0 to 35 ft)								
Soil moisture	9.3	4/43	0	None	3.5 ± 0.9	14 ± 2	32.3 ± 1.6 <sup>c</sup>	pCi/L
Vadose zone (35 to 140 ft)								
Soil moisture	4.5	3/67	0	None	5.6 ± 0.9	22 ± 3	31.6 ± 0.9	pCi/L
Vadose zone (140 to 250 ft)								
Soil moisture	2.0	1/49	0	None	NA	NA	8.7 ± 1.0	pCi/L
Vadose zone (>250 ft)								
Soil moisture	0.0	0/13	0	None	NA	NA	NA	pCi/L
Aquifer	0.0	0/78	0	None	NA	NA	NA	pCi/L
Aquifer field blanks	0.0	0/14	0	None	NA	NA	NA	pCi/L

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. Concentration with a J subscript denote that J data validation qualifier flags were assigned because of analytical quality control anomalies. Results should be used only as estimated quantities.

## 4.7 Tritium

Tritium is produced naturally by interactions of cosmic rays and atmospheric gases and artificially by nuclear reactor operations. Though tritium is not a contaminant of potential concern, it is monitored for several reasons:

- Tritium is a mobile constituent that is collocated with C-14. Both tritium and C-14 are dual-phase constituents that partition into vapor-phase and dissolved-phase components. Thus, tritium monitoring provides trend detection and early indication of possible C-14 migration.
- A substantial fraction of the small amount of tritium (and C-14) released from waste each year migrates to the atmosphere. Distribution and migration are important to the overall understanding of design requirements for a surface barrier, which is an assumed component of future remedial action at the SDA (Holdren and Broomfield 2004).
- Tritium is a contaminant of interest for the ongoing LLW disposal operation (Parsons, Seitz, and Keck 2005).
- Distribution and migration are important to the overall understanding of transport in the vadose zone and in the aquifer because of uncertainties about whether tritium in the aquifer is from the SDA or from upgradient facilities.

Extensive amounts of tritium data have been collected and evaluated over the past 32 years of monitoring at RWMC; however, reporting the entire data set in this RI/BRA is not warranted because tritium is not a contaminant of potential concern. A brief summary of tritium data follows. More complete information is available in the current annual monitoring report (Koeppen et al. 2005) and its predecessors.

Approximately  $2.67\text{E}+06$  Ci of tritium was buried in the SDA according to inventory estimates through 1999, and an additional  $1.12\text{E}+04$  Ci is projected to be added by 2009, for a total of  $2.68\text{E}+06$  Ci.

Samples are routinely collected from lysimeters and vapor ports in the vadose zone, as well as from the aquifer and ambient air around RWMC. Tritium is frequently detected at low concentrations in samples of vadose zone soil-moisture and perched water samples collected from shallow, intermediate, and deep regions of the vadose zone near RWMC. All concentrations are substantially less than the MCL of 20,000 pCi/L. Average tritium concentrations are 650 pCi/L in the shallow vadose zone (i.e., 0 to 11 m [0 to 35 ft]), 1,000 pCi/L at intermediate depths (i.e., 11 to 43 m [35 to 140 ft]), and 700 pCi/L in the deep interval (i.e., 43 to 76 m [140 to 250 ft]). Tritium has not been detected at lysimeter depths greater than 76 m (250 ft).

Tritium in vapor and soil gas is common near buried beryllium blocks. Vapor-phase tritium also has been found at low concentrations throughout much of the vadose zone. Some tritium, primarily in the vicinity of buried beryllium blocks, escapes into the atmosphere each year and is monitored to satisfy requirements for “National Emission Standards for Hazardous Air Pollutants” (40 CFR 61). Estimated emissions of tritium from buried activated beryllium at SVR 20 for Calendar Year 2004 were 2 Ci (Koeppen et al. 2005). Postgrouting tritium results at subsurface sampling ports located 5 and 10 m (16 and 33 ft) laterally from the SVR 20 beryllium blocks show a measurable decrease in activity. However, because tritium concentrations varied significantly and the decrease in activity at each monitoring location was not proportional, conclusions cannot be developed yet about the effectiveness of the grouting. Section 3.1.6 provides more discussion.

In the aquifer near RWMC, tritium is consistently measured in six monitoring wells (i.e., Wells M3S, M7S, M12S, M14S, M16S, and M17S) and is consistently absent in all other wells. Concentrations range from 312 to 2,600 pCi/L, compared to an MCL of 20,000 pCi/L. Tritium concentrations in these six wells are gradually decreasing, and the decrease appears to correlate with the calculated rate of radioactive decay; however, it does not correlate with expected influences from dilution and dispersion. An initial pulse of tritium decayed, dispersed, and diffused over time would decrease much more rapidly, implying that tritium is being added to the aquifer at a rate that exceeds decay effects. Tritium is not detected downgradient of RWMC, and the general pattern of tritium occurrence in RWMC-area wells is not well understood (see Table 4-28). Elevated tritium concentrations in the aquifer around RWMC primarily occur in a small isolated plume northeast of RWMC. The plume does not appear to have any association with the current RTC and INTEC tritium plumes, as evidenced by the lack of tritium detections from Wells M11S and M13S; however, a preliminary study of upgradient influences conducted in 2003 (Roddy and Koeppen 2004) suggests that tritium in the aquifer near RWMC could be from upgradient sources. Waste Area Group 10 has a study in progress that is expected to determine the source of tritium in the aquifer at RWMC.

Table 4-28. Concentration ranges and detection frequencies of tritium for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations (pCi/L)		
					Minimum	Mean	Maximum
Vadose zone (0 to 35 ft)							
Soil moisture	40.5	34/84	0	None	129 ± 34	2,057 ± 179	10,200 ± 802
Vapor	50.0	1/2	0	None	NA	NA	21.6
Vadose zone (35 to 140 ft)							
Soil moisture	31.5	17/54	0	None	174 ± 52	1,066 ± 102	2,950 ± 209
Vapor	31.6	6/19	0	None	0.90	5.6	22
Vadose zone (140 to 250 ft)							
Soil moisture and perched water	24.1	21/87	0	None	169 ± 50	693 ± 83	1,680 ± 101
Vapor	28.6	2/7	0	None	0.50	31.4	62.2
Vadose zone (>250 ft)							
Soil moisture	0.0	0/14	0	None	NA	NA	NA
Vapor	14.3	0/7	0	None	2.7	2.7	2.7
Aquifer	38.8	174/449	0	None	300 ± 87	1,329 ± 154	2,600 ± 400
Aquifer field blanks	0.0	0/24	0	None	NA	NA	NA

Note: Positive tritium detections in the 200 to 300-pCi/L range are questionable because this range is near the limits of detection for soil-moisture samples using standard analysis methodology.

a. Ratio = number of detections above background concentrations/number of sample analysis.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

Note: Positive tritium detections in the 200 to 300-pCi/L range are questionable because this range is near the limits of detection for soil-moisture samples using standard analysis methodology.

a. Ratio = number of detections above background concentrations/number of sample analysis.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

## 4.8 Iodine-129

Iodine-129 is produced from nuclear reactor operations and weapons testing, and it occurs naturally in the environment through interactions of cosmic rays with atmospheric gases and from the spontaneous fission of U-238. It decays by the emission of beta particles and has a  $1.57\text{E}+07$ -year half-life.

**CAVEAT:** *Concentrations of I-129 measured in soil-moisture samples may not be representative of actual concentrations in the vadose zone because the process of sampling soil moisture (i.e., vacuum) may cause a portion of I-129, depending on oxidation conditions, to volatilize from the water sample. While volatilization is thermodynamically favored, it is probably kinetically inhibited. If volatilization is occurring, then measured concentrations may be somewhat lower than actual concentrations in the vadose zone. Detecting I-129 in soil-moisture samples also is complicated by high detection limits (e.g., 40 pCi/L for 50-mL samples).*

This section summarizes I-129 monitoring data for all sample media. No surface soil data are available because I-129 is not a target analyte. Data for the waste zone, vadose zone, and aquifer are evaluated against comparison concentrations shown in Table 4-1 and presented in subsections that follow.

### 4.8.1 Waste Zone

Approximately 0.138 Ci of I-129 was buried in the SDA (through 1999), and an additional 0.0492 Ci is projected to be added by 2009, for a total of 0.188 Ci. Table 4-4 identifies waste streams containing the majority of I-129 activity. Density of I-129 in buried waste is illustrated in Figures 4-6 and 4-7. Figure 4-6 illustrates density for all I-129 in the SDA, while Figure 4-7 illustrates releasable I-129 densities.

**4.8.1.1 Waste Zone Lysimeter Samples.** Attempts are made each quarter to collect samples from Type B and GEOPS lysimeters and to analyze them for a variety of constituents, depending on monitoring objectives for the focus area and sample volume collected. One soil-moisture sample collected from Waste Zone Lysimeter 741-08-L1 in September 2003 had no positive I-129 detection. Because of very small sample volumes, the detection sensitivity achieved for this sample was 1,940 pCi/L. Therefore, the sample could have contained I-129 in concentrations less than the detection limit.

### 4.8.2 Vadose Zone

Distributions of I-129 in vadose zone cores, soil moisture, and perched water in various depth intervals are discussed in the following subsections.

**4.8.2.1 Vadose Zone Core Samples.** Between 1994 and 2003, 63 core samples were analyzed for I-129, with no positive detections. Samples were collected between 1994 and 2003 from the following RWMC-area boreholes: DE3, DE4, DE6, DE7, DE8, I-1S, I-1D, I-2S, I-2D, I-3S, I-4D, I-5S, O-1S, O-1D, O-2S, O-2D, O-3S, O-3D, 2E, 3E, 4E, 5E, 3V, 4V, 5V, 6V, 7V, 8V, 9V, and 10V. Previous core sampling investigations (1971 to 1993) did not analyze for I-129 because it was not a radionuclide of potential concern at that time. Table 4-31 summarizes sample distributions, concentration ranges, detection rates, and exceedances.



**4.8.2.2 Lysimeter Samples at Depths from 0 to 35 ft.** Between 1997 and August 2004, 77 analyses for I-129 were performed on soil-moisture samples collected from 14 shallow-depth lysimeters near RWMC, resulting in three positive detections. Table 4-29 summarizes I-129 detections in the shallow vadose zone samples since routine monitoring began in 1997, and Table 4-31 summarizes sample distributions, concentration ranges, detection rates, and exceedances. Detections occur only sporadically, with no trends. None of the positive sample results could be verified by reanalysis of the original sample. No I-129 has been detected in subsequent samples collected from these lysimeter wells through August 2004.

**4.8.2.3 Lysimeter Samples from 35 to 140 ft Deep.** Twenty-four analyses for I-129 were performed on soil-moisture samples collected from 10 intermediate-depth lysimeters near RWMC between 1997 and August 2004, yielding no positive detections.

**4.8.2.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between 1997 and August 2004, 35 analyses for I-129 were performed on soil-moisture samples collected from 10 lysimeters and three perched water wells, yielding no positive detections. Also, 10 filtered sediment samples from perched water Wells USGS-92 and 8802D were analyzed during this timeframe, with no positive detections.

### **4.8.3 Aquifer**

Between 1994 and May 2004, 461 analyses for I-129 were performed on aquifer samples collected from 16 monitoring wells in the vicinity of RWMC, resulting in five positive detections (see Table 4-30). Because I-129 is not an actinide, replicate analysis was not performed. Three of the five detections exceeded the drinking water MCL of 1 pCi/L; however, all subsequent analyses of samples from these three wells were either nondetects or below the MCL. To reduce uncertainty about I-129 in the aquifer around RWMC, samples collected from RWMC monitoring wells in May 2002, April and May 2003, and April and May 2004 were analyzed at low detection limits (i.e., less than or equal to 0.1 pCi/L), with no positive detections. Iodine-129 has not been detected in any aquifer wells since October 1998 (see Table 4-30). Table 4-31 summarizes sample distributions, concentration ranges, detection rates, and exceedances.

Following routine sample collection in September 1996, seven positive I-129 results were reported. On closer evaluation of the data package, I-129 also was seen to be detected in the corresponding field blank at a concentration equivalent to the sample results ( $3.7 \pm 0.3$  pCi/L). Results from the aquifer wells sampled in this campaign were declared false positive. The September 1996 data were revalidated, and the revised limitations and validation report was reissued (Schaffer 2002).

No USGS I-129 data are available for comparison because USGS does not analyze for I-129 in their eight RWMC monitoring wells.

Table 4-29. Iodine-129 detections in shallow-depth (less than 35 ft) lysimeters since 1997.

Iodine-129 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1	53		29													
	2																
	3																
	4																
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
	4																
For comparison, the maximum contaminant level = 1 pCi/L.																	
		Analysis was performed, but I-129 was not detected.															
		I-129 was detected (pCi/L). Reported concentrations could be biased low (see caveat in Section 4.8).															

Table 4-30. Iodine-129 detections in aquifer wells since 1994.

Iodine-129 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11-A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW2	USGS-127
1994	1																
	2																
	3																
	4																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3																
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1999	1																
	2																
	3																
	4																
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																

Table 4-30. (continued).

Iodine-129 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11-A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW2	USGS-127
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 1 pCi/L.																	
	Analysis performed, but I-129 was not detected.																
	I-129 was detected (pCi/L).																
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.																

#### 4.8.4 Summary of Iodine-129

Evidence is insufficient to conclude that I-129 is present at concentrations above method detection limits in the RWMC vadose zone or aquifer. No detections were observed in core samples; only three unconfirmed and unsupported detections out of 136 sample analyses of soil moisture were observed, and five unconfirmed detections out of 461 aquifer sample analyses were observed. No I-129 detections have been observed in the vadose zone since 1998 or in the aquifer since 2000. The detection frequency associated with soil-moisture and aquifer samples is low. The detection rate of aquifer samples is similar to that of field blanks (see Table 4-31) and therefore is not statistically significant. Detections of ultra-low concentrations of I-129 in the aquifer beneath RWMC are possible because I-129 is routinely detected in upgradient wells near INTEC. Roddy and Koeppen (2004) hypothesize that possible groundwater flow from INTEC could influence the aquifer beneath RWMC.

Because of the volatile nature of I-129, samples obtained by suction lysimeters (vacuum) may not be representative of concentrations in the vadose zone. Iodine-129 may be present at some lysimeter locations but could volatilize during sample collection and yield either a nondetection or a biased-low concentration.

Table 4-31. Concentration ranges and detection frequencies of iodine-129 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Vadose zone (0 to 35 ft)							
Cores	0.0	0/11	0	None	NA	NA	pCi/g
Soil moisture	3.9	3/77	3	98-1, 98-5, W25	22 ± 7	35 ± 10	pCi/L
Vadose zone (35 to 140 ft)							
Cores	0.0	0/26	0	None	NA	NA	pCi/g
Soil moisture	0.0	0/24	0	None	NA	NA	pCi/L
Vadose zone (140 to 250 ft)							
Cores	0.0	0/28	0	None	NA	NA	pCi/g
Soil moisture	0.0	0/26 <sup>c</sup>	0	None	NA	NA	pCi/L
Vadose zone (>250 ft)							
Cores	NA	NA	NA	NA	NA	NA	pCi/g
Soil moisture	0.0	0/9	0	None	NA	NA	pCi/L
Aquifer	1.1	5/461	3	M1S, M7S, M10S	0.59 ± 0.17	4.4 ± 0.5	pCi/L
Aquifer field blanks	2.4	1/42	0	None	NA	NA	pCi/L

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. In addition to the 26 soil-moisture samples, 10 filtered sediment samples from Perched Well USGS-92 were analyzed, with no detections.

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. In addition to the 26 soil-moisture samples, 10 filtered sediment samples from Perched Well USGS-92 were analyzed, with no detections.

## 4.9 Niobium-94

Niobium-94 is a gamma-emitting radionuclide that is an activation product generated during nuclear reactor operations. It decays by the emission of beta particles and has a half-life of  $2.04 \times 10^4$  years.

This section summarizes Nb-94 monitoring data for all media. The sampling data in this section are evaluated against the comparison concentrations in Table 4-1. No surface-soil data were available because Nb-94 is not a target analyte for surface sampling and analysis.

### 4.9.1 Waste Zone

Approximately 134 Ci of Nb-94 was buried in the SDA (through 1999), and an additional 11.8 Ci is projected to be added by 2009, for a total of 146 Ci. Most of the Nb-94 inventory is in the form of reactor core components and end pieces from reactor cores. Table 4-4 identifies waste streams containing the majority of Nb-94 activity. Figure 4-8 shows the density of Nb-94 in buried waste.

**4.9.1.1 Waste Zone Lysimeter Samples.** Attempts are made each quarter to collect samples from Type B and GEOPS lysimeters and to analyze them for a variety of constituents, depending on the monitoring objectives for the focus area and the sample volume collected. Between August 2001 and December 2004, 16 soil-moisture samples were collected from waste zone lysimeters, yielding no positive detections. However, because of small sample volumes, the detection sensitivities achieved for these samples varied from 24 to approximately 4,800 pCi/L. Consequently, concentrations below these detection limits could be present.

### 4.9.2 Vadose Zone

Niobium-94 has not been detected in vadose zone media; therefore, figures showing occurrences are not presented. Monitoring data for Nb-94 in the vadose are limited because lysimeter monitoring began in January 2002. Information about vadose zone data follows.

**4.9.2.1 Vadose Zone Core Samples.** No gamma spectrometry data are available for Nb-94 because Nb-94 was not a target analyte, although Nb-94 would have been detected and reported if concentrations were observed above the method detection limit in routine gamma analysis (i.e., less than 0.1 pCi/g). No detections were reported in vadose zone core sample analyses, suggesting that the gamma analysis did not detect Nb-94 higher than 0.1 pCi/g, which is well below the soil RBC of 387 pCi/g used for comparison.

**4.9.2.2 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.** Niobium-94 was not reported by the laboratory because it was not specified for analysis. However, analytical protocol requires the laboratory to report any positive detection identified in routine gamma analysis spectra, even when the radionuclide is not a specified analyte; therefore, not being reported means Nb-94 was not detected in the soil samples (see Section 4.1.4.6).

**4.9.2.3 Lysimeter Samples from 0 to 35 ft Deep.** Between January 2002 and August 2004, 52 Nb-94 analyses were performed on soil-moisture samples collected from 13 shallow-depth lysimeters near RWMC, with no positive detections.

**4.9.2.4 Lysimeter Samples from 35 to 140 ft Deep.** Between January 2002 and August 2004, 81Nb-94 analyses were performed on soil-moisture samples collected from 13 intermediate-depth lysimeters near RWMC, with no positive detections.

**4.9.2.5 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between January 2002 and August 2004, 100 Nb-94 analyses were performed on samples collected from 19 lysimeters and four perched water wells near RWMC, yielding no positive detections.

### **4.9.3 Aquifer**

Between 1996 and August 2004, 386 gamma analyses were performed on aquifer samples collected from 16 monitoring wells near RWMC, with no positive detections of Nb-94. Reporting Nb-94 results was not specifically requested; therefore, Nb-94 was not reported by the laboratory. However, analytical protocol requires the laboratory to report any positive detection identified in the gamma analysis spectrum, even when the radionuclide is not targeted, and Nb-94 was not reported as being detected in any samples from the aquifer near RWMC. Niobium-94 has never been reported as being detected in any aquifer samples since it became an analyte for routine monitoring in 1996.

The USGS does not analyze for Nb-94 in the eight wells that they manage, control, and routinely sample.

### **4.9.4 Summary of Niobium-94**

Niobium-94 has never been detected in cores, soil-moisture, perched water, or aquifer samples. The limit of detection for large-volume aquifer samples, using gamma spectrometry, is about 3 pCi/L. The detection limit for small-volume soil-moisture or perched water samples is generally about 40 pCi/L, but can vary to about 100 pCi/L or more, depending on the sample volume.

## 4.10 Neptunium-237

Neptunium-237 is an anthropogenic, TRU radionuclide, which is a product of nuclear reactor operations and a decay product of Am-241. It decays by the emission of alpha particles and has a half-life of  $2.14 \times 10^6$  years.

This section summarizes Np-237 monitoring data for all sample media. Sampling data in this section are evaluated against the comparison concentrations shown in Table 4-1. No surface soil data are available because Np-237 is not a target analyte for surface sampling and analysis.

### 4.10.1 Waste Zone

Approximately 0.118 Ci of Np-237 was buried in the SDA (through 1999), and an additional 0.0228 Ci is projected to be added by 2009, for a total of 0.141 Ci. Table 4-4 identifies waste streams containing the majority of Np-237 activity. Figure 4-9 illustrates the density of Np-237 in buried waste. The density map includes ingrowth of 49 Ci of additional Np-237 from the decay of Am-241 and Pu-241.

**4.10.1.1 Waste Zone Spectral Logging.** The spectral gamma moisture logging tool detected Np-237 based on the 312-keV gamma rays from the daughter product, Pa-233. Of the 135 probe holes logged using this tool, 57 (42%) showed the presence of Pa-233 above the noise level. Of the 4,863 total measurements (i.e., all probes and all depths), 511 (11%) showed the presence of Pa-233 above the noise level. The Pa-233 detection limit was approximately 1.7 pCi/g. The maximum and average observed Pa-233 levels were 141 and 5.3 pCi/g, respectively. Logging data are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6) because the detection limit and maximum and average concentrations are based on several assumptions, including that Pa-233 is uniformly distributed in the vicinity of measurement points.

**4.10.1.2 Waste Zone Lysimeter Samples.** Attempts are made each quarter to collect samples from Type B and GEOPS lysimeters and to analyze them for a variety of constituents, depending on the monitoring objectives for the focus area. Type B lysimeters typically yielded inadequate volumes to perform analyses. Five soil-moisture samples were collected from waste zone lysimeters between November 2001 and December 2004, with two positive Np-237 detections measured at concentrations of  $6.1 \pm 1.7$  and  $22 \pm 6$  pCi/L. Both detections occurred in the Americium/Neptunium Focus Area at Lysimeter 741-08-L1. Neptunium-237 concentrations were at levels expected in the waste zone. One detection occurred in November 2001 and the other in April 2002; however, subsequent samples collected from this focus area in August 2002 and September 2003 did not contain detectable amounts of Np-237.

### 4.10.2 Vadose Zone

Though it can be mobile, Np-237 has never been detected in vadose zone soil-moisture and perched water samples since it became a vadose zone analyte in 2000. Results for Np-237 are presented in the following sections for soil and soil-moisture samples.

**4.10.2.1 Core Samples.** During FY 2004, 13 Np-237 analyses were performed on interbed core samples collected from five wells drilled in the SDA, yielding no positive detections. Historical core investigations have not analyzed for Np-237.

**4.10.2.2 Lysimeter Samples from 0 to 35 ft Deep.** Between January 2000 and August 2004, 61 Np-237 analyses were performed on soil-moisture samples collected from 13 shallow-depth lysimeters near RWMC, with no positive detections.



**4.10.2.3 Lysimeter Samples from 35 to 140 ft Deep.** Between January 2000 and August 2004, 62 Np-237 analyses were performed on soil-moisture samples collected from 14 intermediate-depth lysimeters near RWMC, with no positive detections.

**4.10.2.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between January 2000 and August 2004, 43 Np-237 analyses were performed on samples collected from 15 lysimeters and three perched water wells in and around RWMC, with no positive detections.

### **4.10.3 Aquifer**

Between 1998 and May 2004, 345 Np-237 analyses were performed on aquifer samples collected from 16 monitoring wells near RWMC, resulting in four positive detections (see Table 4-32). None of the concentrations exceeded the MCL of 15 pCi/L (total alpha). Each detection occurred in a different monitoring well. Though replicate analysis was performed, none of the detections were confirmed, and subsequent sampling events have not yielded detections. Therefore, a figure showing monitoring results is not presented.

The USGS does not analyze for Np-237 in the eight RWMC wells they manage, control, and routinely sample.

### **4.10.4 Summary of Neptunium-237**

Neptunium-237 has been detected in the waste zone with the spectral gamma moisture logging tool. Also, two detections occurred in waste zone soil-moisture samples collected from the Americium/Neptunium Focus Area in 2001 and in 2002. Positive detections were not observed in subsequent samples from this or any other regions of the waste zone. Neptunium-237 has not been detected in the vadose zone or perched water. Though four aquifer samples showed positive detections for Np-237, none were confirmed by reanalysis or subsequent sampling. Four low-level detections in 345 aquifer sample analyses equate to a detection rate of approximately 1%. Table 4-32 provides the detection frequencies and concentration ranges.

Table 4-32. Concentration ranges and detection frequencies of neptunium-237 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Range of Detected Concentrations			Units
				Minimum	Mean	Maximum	
Vadose zone (0 to 35 ft)							
Cores	NA	NA	NA	NA	NA	NA	pCi/g
Soil moisture	0.0	0/61	0	NA	NA	NA	pCi/L
Vadose zone (35 to 140 ft)							
Cores	0.0	0/1	0	NA	NA	NA	pCi/g
Soil moisture	0.0	0/62	0	NA	NA	NA	pCi/L
Vadose zone (140 to 250 ft)							
Cores	0.0	0/12	0	NA	NA	NA	pCi/g
Soil moisture	0.0	0/36	0	NA	NA	NA	pCi/L
Vadose zone (>250 ft)							
Cores	NA	NA	NA	NA	NA	NA	pCi/g
Soil moisture	0.0	0/7	0	NA	NA	NA	pCi/L
Aquifer	1.2	4/345	0	0.07 ± 0.02	0.20 ± 0.03	0.38 ± 0.04	pCi/L
Aquifer field blanks	0.0	0/24	0	NA	NA	NA	pCi/L

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

## **4.11 Protactinium-231**

Protactinium-231 is a radioactive decay product in the naturally occurring actinium series (see Section 4.1.2.2 and Figure 4-33). Waste buried in the SDA contained only a small amount of Pa-231 at the time of disposal; however, Pa-231 inventories will increase over time through ingrowth attributable to isotopes in the actinium series (see Section 4.1.2.2 and Figure 4-33). After 1,000 years, approximately 0.1 Ci of Pa-231 would be present. Protactinium-231 has not been detected in the SDA because it has not been a targeted analyte. Protactinium-231 decays by alpha emission and has a half-life of  $3.28 \times 10^4$  years. Because the inventory is primarily due to ingrowth, a density map is not provided for Pa-231. Though Pu-239 also is a predecessor, inventories for Pa-231 would be produced primarily by U-235 (see Section 4.18). Figure 4-21 identifies the densities of U-235 in buried waste.

## **4.12 Lead-210**

Lead-210 is a radioactive decay product in the naturally occurring uranium series (see Section 4.1.2.2 and Figure 4-32). Waste buried in the SDA contained only a small amount of Pb-210 at the time of disposal; however, Pb-210 inventories will increase over time through ingrowth attributable to isotopes in the uranium series (see Figure 4-32). After about 200 years, the Pb-210 activity will peak at about 60 Ci. After 1,000 years, approximately 43 Ci of Pb-210 would be present. Lead-210 decays by beta emission and has a half-life of  $2.23 \times 10^1$  years. Because the inventory and associated risk is primarily due to ingrowth, a density map is not provided for Pb-210. Though Pu-238 and U-238 also are predecessors, inventories for Pb-210 would be produced primarily by Ra-226 (see Section 4.14). Figure 4-13 identifies densities of Ra-226 in buried waste.

## 4.13 Plutonium-238, Plutonium-239, and Plutonium-240

All plutonium isotopes are anthropogenic and TRU products of nuclear reactor operations or nuclear weapons production, deployment, and testing. Plutonium-238, -239, and -240 decay by emission of alpha particles and have half-lives of 87.7, 2.41E+04, and 6.56E+03 years, respectively.

Plutonium-239 concentrations quantified by alpha spectrometry analysis methods are often reported by laboratories as Pu-239, Pu-239/240, or Pu-239+240. Any of the three reporting conventions is acceptable, but technically, it is most correct to report Pu-239 as either Pu-239/240 or Pu-239+240 because the individual isotopes cannot be chemically separated and they have alpha particle energies that are nearly identical. Therefore, differentiating among the isotopes using routine alpha spectroscopy is nearly impossible. Nonradiochemical methods such as mass spectrometry must be applied to obtain results for each separate isotope.

Data analysis for Waste Area Group 7 includes evaluating Pu-238:Pu-239/240 activity ratios to determine whether the source of plutonium is from weapons-grade or reactor-grade plutonium. Weapons-grade plutonium contains much more Pu-239/240 than Pu-238, with a Pu-238:Pu-239/240 ratio of approximately 0.02:1 to 0.03:1. Reactor-grade plutonium contains more Pu-238 activity than Pu-239/240, with a Pu-238:Pu-239/240 ratio around 11:1. Detections of Pu-238 without Pu-239/240 could imply reactor-grade plutonium; however, it also could indicate the result is false positive (see following caveat).

**CAVEAT:** *Some low-level detections of Pu-238 could be false positives. A study conducted at the Savannah River Site shows the occurrence of false positive results for Pu-238 can be fairly common at commercial laboratories (Kubilius et al. 2004). False positives for Pu-238 determined by alpha spectroscopy are attributed to interference from small quantities of natural Th-228 that are not completely removed from the sample during chemical separation (Kubilius et al. 2004). At very low concentrations, determining whether a reported, stand-alone Pu-238 detection is false positive is nearly impossible. Therefore, the data evaluator or user can only speculate on its validity based on analytical experience and knowledge together with an understanding of the waste type(s) near the sample location.*

This section summarizes plutonium monitoring data for all media. Sampling data in this section are evaluated against the comparison concentrations in Table 4-1.

### 4.13.1 Waste Zone

Approximately 2.08E+03 Ci of Pu-238, 6.41E+04 Ci of Pu-239, and 1.46E+04 Ci of Pu-240, primarily from Rocky Flats Plant, were buried in the SDA (through 1999). An additional amount of alpha-contaminated LLW (i.e., waste with TRU concentrations less than 10 nCi/g), including 4.91E-01 Ci of Pu-238, 5.07E-01 Ci of Pu-239, and 1.83E-01 Ci of Pu-240, is projected to be added by 2009, which will have a negligible effect on totals. The majority of plutonium is from weapons manufacturing waste, but INL reactor operations also contributed a portion. Tables 4-4 and 4-5 list waste streams containing the majority of Pu-238, -239, and -240. Figures 4-10, 4-11, and 4-12 illustrate densities in the waste zone.

**4.13.1.1 Waste Zone Spectral Logging.** Spectral gamma logging provided data for Pu-239 but no data for Pu-238 or Pu-240. The gamma-ray abundances and energies of Pu-238 and Pu-240 are too low to reliably measure, whereas data obtained for Pu-239 are based on a higher-energy gamma ray (i.e., 414 keV). Of the 135 probe holes logged using the spectral gamma-logging tool, 100 (74%) showed the presence of Pu-239 above the noise level. Of the 4,863 total measurements collected from all probes

at all depths, 1,261 (26%) showed the presence of Pu-239 above the noise level. The Pu-239 detection limit was approximately 29 nCi/g (2.9E+04 pCi/g). The maximum and average observed Pu-239 concentrations were 194,171 nCi/g (1.94E+08 pCi/g) and 2,246 nCi/g (2.2E+06 pCi/g), respectively. Logging data are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6) because the detection limit, maximum concentration, and average concentration are based on several assumptions, including that Pu-239 is uniformly distributed in the vicinity of measurement points.

**4.13.1.2 Waste Zone Lysimeter Samples.** Attempts are made each quarter to collect samples from Type B and GEOPS lysimeters and to analyze them for a variety of constituents, depending on the monitoring objectives for the focus area. Type B lysimeters typically yielded inadequate volumes to perform analyses, so new probes were designed and installed. Between August 2001 and December 2004, 14 Pu-238 and 14 Pu-239/240 analyses were performed on soil-moisture samples collected from eight waste zone lysimeters in the SDA, with three Pu-238 detections and six Pu-239/240 detections. Plutonium-238 detections varied from  $0.18 \pm 0.02$  pCi/g to  $538 \pm 64$  pCi/L, and Pu-239/240 concentrations varied from  $12.2 \pm 0.5$  pCi/g to  $25,600 \pm 1,840$  pCi/L. One Pu-238 and two Pu-239/240 detections occurred in the Americium/Neptunium Focus Area in 2001 and 2002. Two Pu-238 and two Pu-239/240 detections were from lysimeters in the Depleted Uranium Focus Area, and the other two Pu-239/240 detections were associated with soil moisture collected from the Organic Sludge Focus Area in June 2004.

Samples collected from the Depleted Uranium Focus Area were the first quarter that samples were attempted from the recently installed GEOPS lysimeters and yielded adequate sample volumes to perform several analyses. Concentrations of Pu-238 and Pu-239/240 were high and accompanied by high concentrations of Am-241 and VOCs.

Isotopic ratios of plutonium indicate the waste is from weapons manufacturing, and the organic compounds were determined to be characteristic of Series 743 sludge originating from Rocky Flats Plant. Detected organic compounds and radionuclides at this sampling location were compared to waste disposal inventories in this area, and a good correlation was noted. Results suggest that lysimeters sampled in the Depleted Uranium Focus Area are seated within buried waste drums because the samples are representative of waste product.

#### 4.13.2 Surface

Between 1994 and 2004, 356 soil samples were collected near RWMC. Based on gamma spectrometry analysis results, 95 samples were selected for Pu-238 and Pu-239/240 analysis. Seven positive detections of Pu-238 were identified ranging from  $(4.41 \pm 1.36)E-03$  pCi/g at Lysimeter RW 3-4 in 2003 to  $(3.19 \pm 0.53)E-02$  pCi/g in the Pad A area in 2001. Seventy-eight positive detections of Pu-239/240 were identified, ranging from  $(4.73 \pm 1.45)E-03$  pCi/g at the spreading-area control location in 2003 to  $1.22 \pm 0.12$  pCi/g at the active area in 2001. All surface soil concentrations were less than the soil RBCs of 29 pCi/g (Pu-238) and 29 pCi/g (Pu-239/240) used for comparison. The high number of Pu-239/240 detections compared to Pu-238 suggests plutonium from weapons manufacturing waste in the SDA and fallout attributable to historical atmospheric bomb testing. Plutonium in surface soil around RWMC and parts of the INL Site, from the SDA, is briefly described in Section 4.13.5.3.

Between 1990 and 2004, 162 vegetation samples were collected from RWMC and control locations. Based on gamma spectrometry analysis results, 49 samples were evaluated for Pu-238 and Pu-239/240. One positive detection of Pu-238 was identified, and it had a concentration of  $(5.84 \pm 1.61)E-04$  pCi/g at Lysimeter RW 2 in 2002; however, 15 positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 in vegetation samples ranged from

$(4.58 \pm 0.15)E-04$  pCi/g at Lysimeter RW 2 in 2002 to  $(2.42 \pm 0.27)E-02$  pCi/g at Lysimeter RW 2 in 2002. The higher number of Pu-239/240 detections compared to Pu-238 suggests plutonium from weapons manufacturing waste in the SDA and fallout generated by bomb testing.

Between 1991 and 2004, 237 samples of surface run-off water were collected from RWMC and control locations. Based on gamma spectrometry results, 103 samples were evaluated for Pu-238 and Pu-239/240. No positive detections of Pu-238 were identified; however, nine positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 ranged from  $(1.98 \pm 0.65)E-02$  pCi/L at TSA-2 in 2001 to  $(1.1 \pm 0.3)E-01$  pCi/L at TSA-2 in 1995. The high number of Pu-239/240 detections compared to Pu-238 suggests plutonium from weapons manufacturing waste in the SDA and global fallout.

#### **4.13.3 Vadose Zone**

The distribution of plutonium in vadose zone core, soil moisture, and perched water in the various depth intervals is discussed in the following subsections.

##### **4.13.3.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.**

The samples were analyzed for plutonium isotopes, and Pu-238 was detected in one of the samples at a concentration of  $0.051 \pm 0.009$  pCi/g, whereas Pu-239/240 was not detected in any of the samples. The sample concentration was less than the soil RBC used for comparison (29 pCi/g) but exceeded surficial soil background upper tolerance limit (0.009 pCi/g) (see Section 4.1.4.5).

**4.13.3.2 Vadose Zone Core Samples.** Between 1971 and 2003, 354 vadose zone core samples collected during well drilling were analyzed for Pu-238, and 365 were analyzed for Pu-239/240. Eighteen positive Pu-238 detections and 29 positive Pu-239/240 detections were identified, using less-than-soil RBCs for comparison; some exceeded INL Site surface soil background concentrations. Of the 18 Pu-238 detections, 13 exceeded the surface soil background of 0.0049 pCi/g, and 14 of the 29 Pu-239/240 detections exceeded surface soil background of 0.10 pCi/g. Four of the 13 Pu-238 results and nine of the 14 Pu-239/240 results were analyzed in 1971 and 1972, and the data are of questionable quality because of potential cross-contamination (see Section 4.1.6.4).

The most recent core sampling (i.e., 2004) focused on the B-C and C-D sedimentary interbeds beneath RWMC. Plutonium was not detected in any of the 13 interbed samples collected in FY 2004. The FY 2004 Pu-238 and Pu-239/240 results (i.e., nondetections) are not comparable to previous core sample detections because samples were not collected at the same interbed locations. The only core locations near one another are DE4 (2004) and I4D (2000) in the southwestern corner of Pad A. Plutonium-238 and Pu-239/240 results of DE4 and I4D, at comparable depths, correlate reasonably well because plutonium was not detected in either of these core samples.

The majority of valid plutonium detections (i.e., those not taken between 1971 and 1974) are located in the Pit 5 area (i.e., Wells 79-2, D02, and TW1) and the western part of the SDA (i.e., Wells 76-3, 78-5, I-3S, USGS-93, and USGS-96). Tables 4-46 and 4-47 list concentration ranges, detection frequencies, and exceedances for Pu-238 and Pu-239/240, respectively.

**4.13.3.3 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1997 and August 2004, 152 analyses for Pu-238 and 153 analyses for Pu-239/240 on soil-moisture samples collected from 17 shallow-depth lysimeters near RWMC resulted in seven Pu-238 detections and one Pu-239/240 detection. Occurrences of Pu-238 and Pu-239/240 in the shallow vadose zone since monitoring began in 1997 are depicted in Tables 4-33 and 4-34, respectively.

More Pu-238 detections occurred than Pu-239/240 detections, which does not parallel disposal records because the majority of plutonium in the SDA is from weapons manufacturing waste, which is predominantly composed of Pu-239/240. Some of the positive Pu-238 detections may be false positives (see Section 4.1.6.2). Also, where Pu-238 and Pu-239/240 detections occurred together (i.e., PA02:L16), the isotopic ratio (5.3:1) is more characteristic of reactor operations waste (11:1) than of weapons waste (0.02:1 to 0.03:1). Similarly, locations where Pu-238 was detected but Pu-239/240 was not detected also can be indicative of waste from reactor operations. Lysimeter wells showing possible reactor-generated plutonium (Wells PA01, PA02, and PA03) are located near Pad A. These same lysimeters, plus others near Pad A, also have elevated levels of anthropogenic uranium, implying reactor-generated plutonium. The presence of Pu-238 at Well 98-4 and 98-5 is highly questionable because detections were not confirmed, results could be false positives (see earlier caveat), and subsequent monitoring has not yielded any additional detections.

Table 4-33. Plutonium-238 detections in shallow (less than 35 ft) lysimeters since 1997.

Plutonium-238 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																
	2																
	3																
	4							24									
1998	1																
	2							2.2									
	3			5.6		8.5											
	4																
1999	1																
	2																
	3																
	4																
2000	1																
	2																
	3																
	4		0.88			2.3											
2001	1						3.7										
	2																
	3																
	4																

Table 4-33. (continued).

Plutonium-238 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
	4																
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).																	
		Analysis was performed, but Pu-238 was not detected.															
		Pu-238 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.13).															



Table 4-34. Plutonium-239/240 detections in shallow (less than 35 ft) lysimeters since 1997.

Plutonium-239/240 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
	4																

Note: The highest result is reported for duplicate samples or reanalysis.  
For comparison, the maximum contaminant level = 15 pCi/L (total alpha).

	Analysis was performed, but Pu-239/240 was not detected.
	Pu-239/240 was detected (pCi/L).

**4.13.3.4 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1997 and August 2004, 116 analyses for Pu-238 and 116 analyses for Pu-239/240 of soil-moisture samples collected from 14 intermediate-depth lysimeters near RWMC resulted in three positive Pu-238 and three Pu-239/240 detections. Historical occurrences of Pu-238 and Pu-239/240 at intermediate depths since monitoring began in 1997 are depicted in Table 4-35 and Table 4-36, respectively.

Positive detections could not be confirmed by reanalysis or corroborated during succeeding sampling events. Therefore, the presence of plutonium at these monitoring locations in the 35 to 140-ft depth interval is unlikely.

Table 4-35. Plutonium-238 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Plutonium-238 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
1997	1														
	2														
	3														
	4	11.6	3.3	3.1											
1998	1														
	2														
	3														
	4														
1999	1														
	2														
	3														
	4														
2000	1														
	2														
	3	0													
	4	0													
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														

Table 4-35. (continued).

Plutonium-238 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
2003	1														
	2														
	3														
	4														
2004	1														
	2														
	3														
	4														
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).															
		Analysis was performed, but Pu-238 was not detected.													
		Pu-238 was detected (pCi/L). Some reported results could be false positives (see caveat in Section 4.13).													

Table 4-36. Plutonium-239/240 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Plutonium-239/240 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
1997	1														
	2														
	3														
	4			1.1											
1998	1														
	2														
	3														
	4														
1999	1														0.34
	2														
	3														
	4														
2000	1														
	2														
	3														
	4														

Table 4-36. (continued).

Plutonium-239/240 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
2001	1											3.3			
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														
2003	1														
	2														
	3														
	4														
2004	1														
	2														
	3														
	4														
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).															
		Analysis was performed, but Pu-239/240 was not detected.													
		Pu-239/240 was detected (pCi/L).													

**4.13.3.5 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** A total of 141 analyses for Pu-238 and 144 analyses for Pu-239/240 of samples collected from 20 lysimeters and three perched water wells near RWMC resulted in six detections. Except for USGS-92, which has been sampled since 1972, all results were collected between 1997 and August 2004. Plutonium has been detected six times—four Pu-238 and two Pu-239/240 detections. Of these six detections, two were associated with filtered sediment. Historical detections of Pu-238 and Pu-239/240 in the deep regions of the vadose zone are depicted in Table 4-37 and Table 4-38, respectively.

Again, Pu-238 is detected more frequently than Pu-239/240, which is not consistent with weapons manufacturing waste in SDA containing mostly Pu-239/240. Some of the positive Pu-238 detections may be false positives (see Section 4.1.6.2). Plutonium-238 and Pu-239/240 were not detected together in the same sample. Consequently, isotopic ratios needed to establish the origin of plutonium at this deep location could not be determined. Plutonium has not been detected in soil-moisture samples or perched water wells at this depth interval since 2000, and some of the historical Pu-238 detections could be false positives. Therefore, plutonium beyond the 140-ft region (i.e., the B-C interbed) is not likely.

Table 4-37. Plutonium-238 detections in deep (greater than 140 ft) lysimeters and perched water since 1972.

Plutonium-238																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898 :DL40	TW1: DL03	USGS -092
1972	4																						
1973	1																						
1974	3																						
1975	—																						0.025
1976	2																						
1977	1 and 3																						
1978	—																						
1979 to 1989																							
1990	—																						
1991	—																						
1992	1 and 3																						
1993	1																						
1994	—																						
1995	1																						0.39
1996	2																						
1997	1																						
	2																						
	3																						
	4																						1.4*
1998	1																						
	2																						
	3																						
	4																						
1999	1																						
	2																						
	3																						
	4																						

Table 4-37. (continued).

Plutonium-238																						
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																						
Fiscal Year	Quarter 8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898 :DL40	TW1: DL03	USGS -092
2000	1																					
	2																					
	3																					
	4																					
2001	1																					
	2																					
	3																					
	4																					
2002	1																					
	2																					
	3																					
	4																					
2003	1																					
	2																					
	3																					
	4																					
2004	1																					
	2																					
	3																					
	4																					
Note: The highest result is reported for duplicate samples or reanalysis. * = Result is for filtered sediment, not filtrate. For comparison, the maximum contaminant level = 15 pCi/L total alpha.																						
Analysis was performed for Pu-238, but none was detected.																						
Pu-238 was detected (pCi/L), but some reported results could be false positives (see caveat in Section 4.13).																						

Table 4-38. Plutonium-239/240 detections in deep (greater than 140 ft) lysimeters and perched water since 1972.

Plutonium-239/240																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898 :DL40	TW1: DL03	USGS-092
1972	4																						
1973	1																						
1974	3																						
1975	—																						
1976	2																						
1977	1 and 3																						
1978	—																						
1979 to 1989																							
1990	—																						
1991	—																						
1992	1 and 3																						
1993	1																						
1994	—																						
1995	1																						
1996	2																						
1997	1																						
	2																						
	3																						
	4																						
1998	1																						
	2																						0.32*
	3																						
	4																						
1999	1																						
	2																						
	3																						
	4																						

Table 4-38. (continued).

Plutonium-239/240																								
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																								
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898 :DL40	TW1: DL03	USGS-092	
2000	1																							
	2																							
	3																	2.7						
	4																							
2001	1																							
	2																							
	3																							
	4																							
2002	1																							
	2																							
	3																							
	4																							
2003	1																							
	2																							
	3																							
	4																							
2004	1																							
	2																							
	3																							
	4																							
Note: The highest result is reported for duplicate samples or reanalysis.																								
* = Result is for filtered sediment, not filtrate.																								
For comparison, the maximum contaminant level = 15 pCi/L total alpha.																								
Analysis was performed for Pu-239/240, but none was detected.																								
Pu-239/240 was detected (pCi/L).																								



#### 4.13.4 Aquifer

Between October 1992 (when routine monitoring began) and May 2004, 460 analyses for Pu-238 and 462 analyses for Pu-239/240 (of aquifer samples) were collected from 16 INL Site monitoring wells near RWMC, resulting in 13 positive Pu-238 detections and four Pu-239/240 detections (see Table 4-39 and Table 4-40, respectively). None of the detections exceeded the MCL, except for an unconfirmed Pu-239/240 result from Well M4D in November 1993; this detection was not confirmed by reanalysis or by analysis of a duplicate sample. None of the historical detections were confirmed by reanalysis, except for two Pu-238 samples in October 2000 (Wells M7S and M11S). However, Pu-238 detections in October 2000 are questionable (see following discussion). Plutonium has not been detected in subsequent samples obtained from these monitoring wells.

Again, the disproportionate number of Pu-238 detections compared to Pu-239/240 detections, which is more indicative of reactor operations, not weapons production, should be noted. Waste from weapons manufacturing primarily comprises Pu-239/240 (i.e., 99.6% by weight) and very little Pu-238 (0.01% by weight). Some of the positive Pu-238 detections may be false positive (see Section 4.1.6.2) or associated with reactor operations waste, which contains about 10 times more Pu-238 activity than Pu-239/240 activity.

Eight Pu-238 results, initially reported as positive detections in 2000, were reevaluated in 2001 and reclassified as false positives. The results were identified as false positive because Pu-238 was detected in the corresponding September 2000 field blank sample at a concentration equivalent to that found in the aquifer samples. The September 2000 data were therefore revalidated, and a revised limitations and validations report was issued (Schaffer 2002).

The field blank associated with the October 2000 aquifer samples, however, showed no indication of Pu-238 contamination. Seven of the 10 Pu-238 detections occurred in October 2000. The large number of positive Pu-238 detections from the October 2000 sampling event is unusual. These positive, low-level Pu-238 detections were carefully scrutinized by ICP and USGS scientists, and no analytical anomalies were found; however, the October 2000 results from the INL Site are questionable for the following reasons:

- Samples from Wells M1S and M3S are routinely cosampled by ICP, USGS, and INL Oversight Program. The radioanalytical results are used for comparative purposes to help confirm the presence or absence of measured radionuclides. Samples collected by the INL Oversight Program in October 2000 showed one detection from Well M1S and one nondetection from Well M3S (see Table 4-41). None of the USGS samples between 1993 and April 2001 showed positive detections for Pu-238, including the sample from October 2000. Comparative results provide conflicting evidence about the presence of Pu-238 in samples collected from Wells M1S and M3S.
- Other actinides (e.g., Pu-239/240 and Am-241) were not detected with Pu-238, which is unusual for contamination emanating from waste generated by weapons manufacturing.
- Because of inconsistent results, potential for cross-contamination at the analytical laboratory was examined. No issues were identified; however, additional quality control samples were specified for subsequent sampling events to increase confidence in analytical results for low-level detections at concentrations very close to the method detection limit.
- A statistical study of all plutonium data indicated that the cluster of detections in October 2000 was statistically anomalous and that the Pu-238 detections were most likely from a source other than the aquifer (Leecaster 2004).

Table 4-39. Plutonium-238 detections in aquifer wells since October 1992.

Plutonium-238 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS- 127
1993	1																
	2																
	3																
	4																
1994	1																
	2																
	3																
	4																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3																
	4																
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																

Table 4-39. (continued).

Plutonium-238 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS- 127
1999	1																
	2																
	3													0.044			
	4																
2000	1																
	2																
	3																
	4											0.37					
2001	1		0.018	0.030							0.019		0.028		0.071		
	2													0.17			
	3																
	4								0.034								
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3												0.102				
	Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L total alpha.																
	Analysis was performed, but Pu-238 was not detected.																
	Pu-238 was detected (pCi/L), but some reported results could be false positives (see caveat in Section 4.13).																
	Well is out of service. Well was rendered inoperable after attempts at repairs were unsuccessful.																

Table 4-40. Plutonium-239/240 detections in aquifer wells since October 1992.

Plutonium-239/240 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS- 127
1993	1																
	2																
	3												4.3				
	4																
1994	1												1.3				
	2																
	3																
	4																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3																
	4																
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																

Table 4-40. (continued).

Plutonium-239/240 Radioactive Waste Management Complex Aquifer Monitoring Wells																		USGS- I27
Fiscal Year	Quarter	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2		
2000	1																	
	2																	
	3																	
	4											0.09						
2001	1																	
	2																	
	3																	
	4								0.03									
2002	1																	
	2																	
	3																	
	4																	
2003	1																	
	2																	
	3																	
	4																	
2004	1																	
	2																	
	3																	
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).																		
	Analysis was performed, but Pu-239/240 was not detected.																	
	Pu-239/240 was detected (pCi/L).																	
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.																	

Table 4-41. Plutonium-238 detections in cosampled Wells M1S and M3S during September and October 2000.

Sampler	September 2000		October 2000	
	M1S	M3S	M1S	M3S
Idaho Cleanup Project	Not detected	Detected	Detected	Not detected
U.S. Geological Survey	Not sampled	Not sampled	Not detected	Not sampled
Idaho National Laboratory Oversight Program	Not detected	Not detected	Detected	Not detected

After this cluster of Pu-238 detections in 2000, numerous improvements were made to the sampling and analytical protocols to increase confidence in the analytical results for low-level detections at concentrations very close to the method detection limit (see Section 4.1.6). Sampling, analytical, and data reporting protocols now require an equipment rinsate and a certified, sealed quality control blank that is not opened until it arrives at the analytical laboratory. Also, the laboratory created a clean room for processing and preparing very low-level samples.

In addition to aquifer monitoring routinely conducted by INL, USGS manages, controls, and routinely samples eight other aquifer wells near RWMC. These eight wells have been monitored by USGS for Pu-238 and Pu-239/240 since 1972. Between 1972 and 2003, 522 Pu-238 and 518 Pu-239/240 analyses were performed. Sixteen Pu-238 detections and six Pu-239/240 detections were observed during this interval. The distribution of Pu-238 and Pu-239/240 detections in USGS aquifer samples is shown in Tables 4-42, 4-43, 4-44, and 4-45, respectively. The concentrations of all detections are less than the MCL. Fifteen of the 16 Pu-238 detections and five of the six Pu-239/240 detections occurred between 1972 and 1974, shortly after the wells were drilled and installed. The 1972 to 1974 detections are questionable because of potential cross-contamination (see Section 4.1.6.4) (Barraclough et al. 1976). Since 1975, plutonium has been detected only twice—once in 1976 and once in 1983. Both were samples collected from Well USGS-88.

Again, the inordinate number of Pu-238 detections compared to Pu-239/240 detections is very unusual, especially if plutonium from weapons manufacturing is assumed to be the source. In cases where Pu-238 and Pu-239/240 were both detected in the same sample, isotopic ratios are not indicative of either weapons production or reactor operations, supporting the conclusion that some of the Pu-238 detections are false positives (see caveat in Section 4.13).

Table 4-42. Plutonium-238 detections in U.S. Geological Survey aquifer wells from 1972 through 1992.

Plutonium-238 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1972	1				0.96				
	2								
	3				9.00				
	4								
1973	1								
	2	0.040	0.27						
	3			0.040	0.13				
	4	0.080	0.040	0.021					
1974	1				0.035				
	2		0.033	0.040					
	3								
	4								
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4								
1977	1								
	2								
	3								
	4								
1978	1								
	2								
	3								
	4								
1979	1								
	2								
	3								
	4								
1980	1								
	2								
	3								
	4								

Table 4-42. (continued).

Plutonium-238 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1981	1								
	2								
	3								
	4								
1982	1								
	2								
	3								
	4								
1983	1								
	2		0.81						
	3								
	4								
1984	1								
	2								
	3								
	4								
1985	1								
	2								
	3								
	4								
1986	1								
	2								
	3								
	4								
1987	1								
	2								
	3								
	4								
1988	1								
	2								
	3								
	4								
1989	1								
	2								
	3								
	4								



Table 4-42. (continued).

Plutonium-238 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								
1992	1								
	2								
	3								
	4								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).									
a. RWMC Production Well.									
	Analysis was conducted for Pu-238, but none was detected.								
	Pu-238 was detected (pCi/L).								
	Pu-238 detections may be attributable to cross-contamination (see Section 4.1.6.4).								

Table 4-43. Plutonium-238 detections in U.S. Geological Survey aquifer wells from 1993 through 2003.

Plutonium-238 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1993	1								
	2								
	3								
	4								
1994	1								
	2								
	3								
	4								
1995	1								
	2								
	3								
	4								

Table 4-43. (continued).

Plutonium-238 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1996	1								
	2								
	3								
	4								
1997	1								
	2								
	3								
	4								
1998	1								
	2								
	3								
	4								
1999	1								
	2								
	3								
	4								
2000	1								
	2								
	3								
	4								
2001	1								
	2								
	3								
	4								
2002	1								
	2								
	3								
	4								
2003	1								
	2								
	3								
	4								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).									
a. RWMC Production Well.									
	Analysis was conducted for Pu-238, but none was detected.								
	Pu-238 was detected (pCi/L).								

Table 4-44. Plutonium-239/240 detections in U.S. Geological Survey aquifer wells from 1972 through 1992.

Plutonium-239/240 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1972	1								
	2								
	3								
	4								
1973	1								
	2			0.29					
	3								
	4	0.030							
1974	1								
	2	0.030	0.040	0.036					
	3								
	4								
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4		0.040						
1977	1								
	2								
	3								
	4								
1978	1								
	2								
	3								
	4								
1979	1								
	2								
	3								
	4								
1980	1								
	2								
	3								
	4								

Table 4-44. (continued).

Plutonium-239/240 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1981	1								
	2								
	3								
	4								
1982	1								
	2								
	3								
	4								
1983	1								
	2								
	3								
	4								
1984	1								
	2								
	3								
	4								
1985	1								
	2								
	3								
	4								
1986	1								
	2								
	3								
	4								
1987	1								
	2								
	3								
	4								
1988	1								
	2								
	3								
	4								
1989	1								
	2								
	3								
	4								

Table 4-44. (continued).

Plutonium-239/240 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								
1992	1								
	2								
	3								
	4								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha).									
a. RWMC Production Well.									
	Analysis was performed for Pu-239/240, but none was detected.								
	Pu-239/240 was detected (pCi/L).								
	Pu-239/240 detections may be attributable to cross-contamination (see Section 4.1.6.4)								

Table 4-45. Plutonium-239/240 detections in U.S. Geological Survey aquifer wells from 1993 through 2003.

Plutonium-239/240 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1993	1								
	2								
	3								
	4								
1994	1								
	2								
	3								
	4								
1995	1								
	2								
	3								
	4								

Table 4-45. (continued).

Plutonium-239/240 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1996	1								
	2								
	3								
	4								
1997	1								
	2								
	3								
	4								
1998	1								
	2								
	3								
	4								
1999	1								
	2								
	3								
	4								
2000	1								
	2								
	3								
	4								
2001	1								
	2								
	3								
	4								
2002	1								
	2								
	3								
	4								
2003	1								
	2								
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, the maximum contaminant level = 15 pCi/L (total alpha). a. RWMC Production Well.									
		Analysis was conducted for Pu-239/240, but none was detected.							
		Pu-239/240 was detected (pCi/L).							

#### 4.13.5 Plutonium Special Studies

Plutonium isotopes are occasionally detected at low concentrations during routine monitoring. These low concentrations are often near the analytical method detection limit, making it difficult to determine confidently whether the detection is a valid true positive detection, or whether it is a detection from fluctuations in background noise, sample matrix interferences, or analytical anomalies. Over the years, these intermittent, low-level detections have led to speculation that plutonium may exist in the aquifer at concentrations just below the detection sensitivity of traditional radioanalytical methods (i.e., approximately 0.02 to 0.03 pCi/L). As described below, results from analysis with highly sensitive methods (i.e., approximately 0.0002 to 0.002 pCi/L) refute that speculation. Also presented in this section are studies associated with determining isotopic composition of plutonium in surface soil at the INL Site, an estimate of the amount of plutonium released historically from the SDA, and the areal extent of release.

From 1999 through 2000, various samples from monitoring wells near RWMC and other INL Site facilities were analyzed for ultra-low levels of uranium and plutonium. Low-level analyses were performed on these samples to:

- Determine whether low concentrations of plutonium have migrated from the waste zone into the vadose zone and aquifer and whether uranium has an anthropogenic component; and if so, identify the sources of plutonium and uranium (e.g., fallout, nuclear weapons manufacturing waste, and reactor operations waste) using isotopic ratios
- Determine whether low concentrations of plutonium are present in the Snake River Plain Aquifer at the INL Site; and if so, establish background concentrations
- Determine whether sample results previously identified as statistically positive (i.e., greater than  $2\sigma$ , but less than or equal to  $3\sigma$ ) actually contained low levels of plutonium.

**4.13.5.1 Plutonium and Uranium Study Specific to the Radioactive Waste Management Complex.** In July 1999, nine RWMC aquifer monitoring wells, 13 vadose zone lysimeters, and two perched water wells in RWMC were sampled; samples were analyzed to determine whether detected uranium is anthropogenic and whether low levels of plutonium have migrated into the vadose zone or the aquifer beneath RWMC. Water samples were filtered, and both the filtrate and filtered material were analyzed for Pu-239 using the highly sensitive isotope dilution-thermal ionization mass spectrometry methodology (Roback et al. 2001). Analysis results show the following:

- Anthropogenic uranium was detected at two vadose zone locations (i.e., Wells TW1 and 8802D). Uranium at Well TW1 is enriched with U-235 and is depleted at Well 8802D.
- Filtered material from W23:L08 showed a very small component of depleted uranium.
- Concentrations of uranium were observed at Lysimeter Wells D06, PA01, PA02, PA03, and W23; however, isotopic ratios in 1999 indicate the uranium is natural.
- Plutonium-239 was not detected above detection limits (approximately 0.0002 to 0.002 pCi/L) in any of the samples, except for TW1, 8802D, and PA03 filtered material. Measured concentrations of these three samples are near the detection limit but are described as having statistical significance. Results of statistical tests suggest the possibility that Pu-239 may be present in Wells TW1, 8802D, or PA03.

**4.13.5.2 Plutonium and Uranium Aquifer Background Study.** Between August 1999 and March 2000, 46 aquifer wells across the INL Site were sampled, with duplicate samples collected from each well. One set of samples was sent to a subcontracted commercial laboratory for routine analyses, and the other set was sent to Los Alamos National Laboratory for ultra-low-level analyses of plutonium and uranium. Based on results from the commercial laboratory, 15 aquifer samples were selected for low-level analysis. The Los Alamos National Laboratory analyzed samples to determine whether anthropogenic uranium and low concentrations of plutonium were present in groundwater at the INL Site to define background concentrations and identify associated waste-generating processes (i.e., weapons production or reactor operations), based on isotopic ratios. The other reason for sending INL Site aquifer samples for low-level analyses was to ascertain whether samples that showed statistically positive detections of plutonium, using traditional radiochemical methods, actually contained low concentrations of plutonium.

The ultra-low-level analysis provided detection limits for plutonium of 0.00003 pCi/L, about 10 to 100 times lower than previous sensitive techniques (i.e., approximately 0.0002 to 0.002 pCi/L) and about 1,000 times more sensitive than commercial radioanalytical methods (approximately 0.03 pCi/L). The modified technique also provided analytical results for Np-237 at no additional cost. Two separate reports were issued; the first report (Roback 2003a) encompassed 13 uranium analyses and four plutonium analyses, and the second report (Roback 2003b) encompassed 15 plutonium and neptunium analysis results. The analysis results show:

- Plutonium-239 and Np-237 were not detected in any RWMC or INL Site aquifer well samples, except for Well USGS-40 at INTEC
- Though Pu-239 was not identified as positively detected, the numbers of measured atoms for samples from upgradient aquifer Wells M11S and M12S are notably higher than the blank samples and all other aquifer samples
- Uranium concentrations and isotopic ratios for RWMC and INL Site aquifer well samples are typical of natural concentrations in groundwater in the Snake River Plain Aquifer, except for Wells USGS-40, USGS-47, USGS-113, and LF3-08; two of these four wells are located at INTEC (Wells USGS-40 and USGS-47), and two are 1.6 to 3.2 km (1 to 2 mi) downgradient of INTEC and upgradient from RWMC (Wells USGS-113 and L08)
- Samples previously identified with statistically positive concentrations of plutonium showed no evidence of low levels of plutonium.

**4.13.5.3 Isotopic Composition of Plutonium in Surface Soil.** A detailed study of the isotopic composition of plutonium in INL Site surface soil was conducted by Beasley et al. (1998) between 1993 and 1998. The study was a precursor to the Pit 9 interim action retrieval demonstration (i.e., Operable Unit 7-10). The primary focus of the study was to determine isotopic signatures for various sources of plutonium on the INL Site (i.e., global fallout, regional fallout from Nevada Test Site, and local contributions from INL Site operations), so that plutonium released from the SDA in the early years of operation could be distinguished from other sources, and the quantities released from the SDA could be estimated. A total of 123 samples collected at the INL Site and other locations in Idaho, Montana, and Wyoming were analyzed by isotope dilution-thermal ionization mass spectrometry. Approximately 150  $\mu\text{Ci}$  of Pu-239/240 was estimated to have been released from the SDA and distributed over a 28,231-ha (109-m<sup>2</sup>) area extending approximately 48 km (30 mi) northeast and 3.2 km (12 mi) southwest of RWMC. The majority of surface soil samples in this area, including those around RWMC, have plutonium concentrations between 60 and 600 pCi/m<sup>2</sup>. This contribution to the environment at the INL Site is about 14% higher than that from global fallout.



#### 4.13.6 Summary of Plutonium

Plutonium-238 and Pu-239/240 have been detected at very low concentrations in surface soil, vegetation, surface run-off water, and waste zone soil moisture, subsurface core materials, a few vadose zone soil-moisture and aquifer samples, and waste zone probe holes examined with the spectral gamma-logging tool.

**4.13.6.1 Surface.** Low concentrations of plutonium, primarily Pu-239/240, are frequently detected in surface soil and vegetation samples and occasionally in run-off water samples. The preponderance of Pu-239/240 (22% detection frequency) compared to Pu-238 (2%) in surface soil and vegetation samples (i.e., 9% compared to 0.6%) is indicative of weapons manufacturing. Beasley et al. (1998) shows that some Pu-239/240 originates in SDA surface soil (see Section 4.13.5.3), with the remainder attributable to fallout.

**4.13.6.2 Cores.** Approximately 8 to 14% of the core samples collected in the 0 to 35-ft and 35 to 140-ft depth intervals contained detectable amounts of Pu-239/240, compared with 2.4% in the depth interval from 43 to 76 m (140 to 250 ft). Similar fractions of Pu-238 also are found at these depth intervals, but the detection frequencies are lower. Concentrations of detectable Pu-238 and Pu-239/240 in core material from the 0 to 140-ft depth interval are low and range from 0.003 to 1.1 pCi/g; this is less than the soil RBC used for comparison. Plutonium detections in shallow-depth cores occurred near the surface to about 5 m (15 ft); in the intermediate-depth region (35 to 140 ft), all plutonium detections occurred between 30 and 34 m (98 and 111 ft) in the B-C interbed; and in the deep regions (greater than 140 ft), detections all occurred in samples obtained between 230 and 240 ft deep (C-D interbed). Of the plutonium detections, 11% occur above the B-C interbed (0 to 84 ft), 68% occur in the B-C interbed (84 to 141 ft), 19% in the C-D interbed (214 to 257 ft), and 2% below the C-D interbed. Analytical evidence implies that sedimentary interbeds capture or filter out plutonium. This inference agrees with an independent study of the adsorptive properties of sediment in the RWMC interbeds conducted by Batcheller and Redden (2004). Spatially, plutonium detections are clustered in the region below Pit 5 and in the western end of the SDA near Pits 1 and 2.

**4.13.6.3 Soil Moisture and Perched Water.** Detections in soil moisture and perched water are sporadic and generally characterized by low concentrations that are substantially less than the MCL of 15 pCi/L (total alpha) used for comparison (see Figure 4-51). Plutonium in soil moisture does not appear to be widespread in the vadose zone, nor is it prevalent at any specific region, except for a possible cluster of detections around Pad A. Most lysimeters near Pad A have shown several plutonium detections at one time or another. No other soil-moisture or perched water monitoring locations in RWMC exhibit consistent plutonium detections. As shown in Figure 4-51, some detections exhibit concentrations greater than the noise range; however, in all cases, the detections were not replicated or confirmed upon reanalysis, analysis of a duplicate sample, or subsequent sampling events. Many of the detections are one-time detections. Figure 4-52 shows the distribution of Pu-238 and Pu-239/240 detections in the aquifer.

Unlike surface soil samples, the number of Pu-238 detections compared to Pu-239/240 detections in soil moisture and perched water (see Table 4-46 and 4-47) is disproportionate and not consistent with weapons manufacturing waste, which contains very little Pu-238. The prevalence of Pu-238 in soil-moisture and perched water samples at low concentrations suggests either the plutonium may be reactor-generated or Pu-238 sample results are false positives. Shallow-depth lysimeters around Pad A have a higher Pu-238 detection frequency (4.6%) than Pu-239/240 (0.7%), indicating reactor-generated plutonium. Elevated levels of anthropogenic uranium, tritium, C-14, and Tc-99 at these same monitoring locations also imply reactor-generated plutonium.

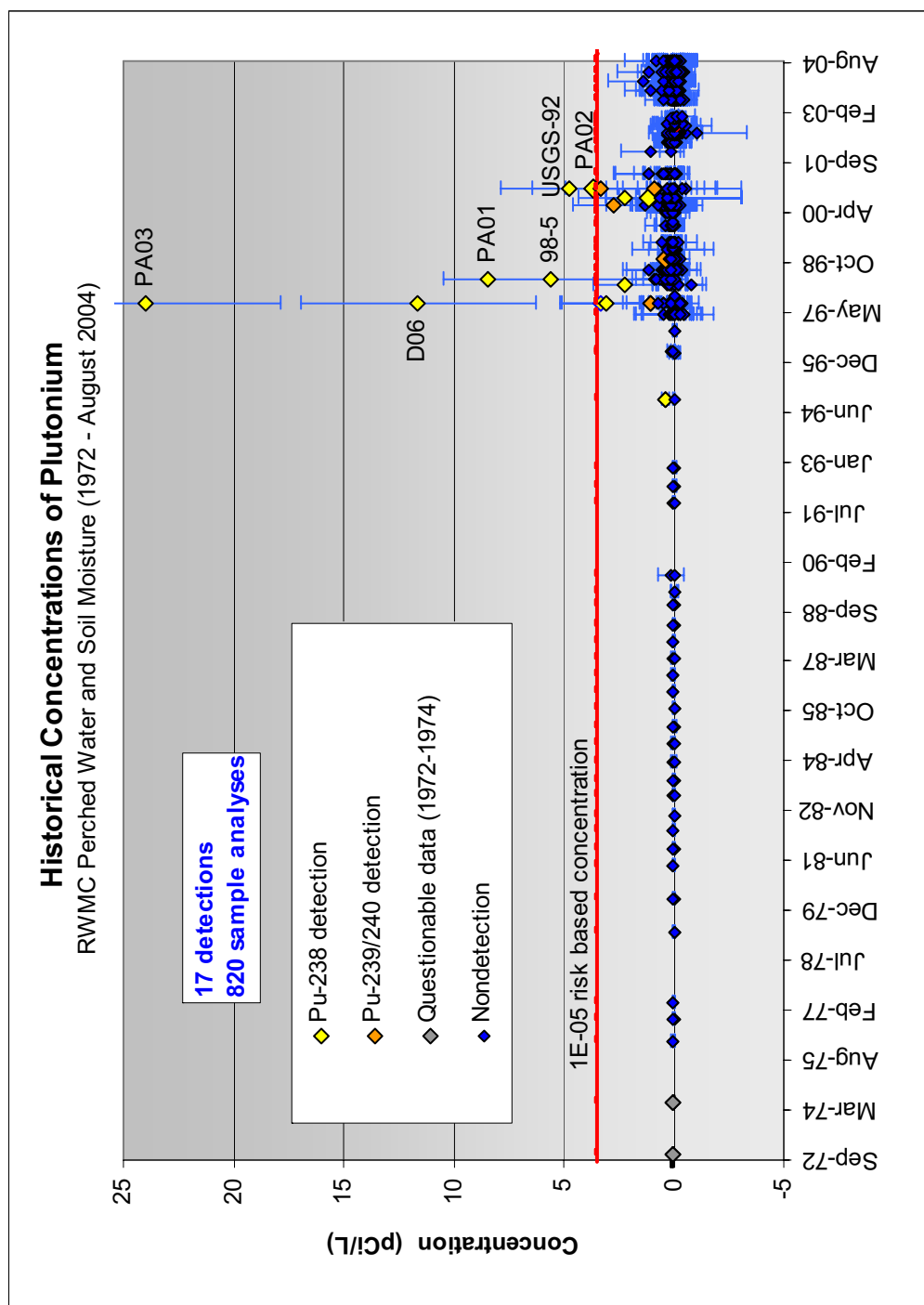


Figure 4-51. Plutonium concentrations in soil moisture and perched water from 1972 to 2004.

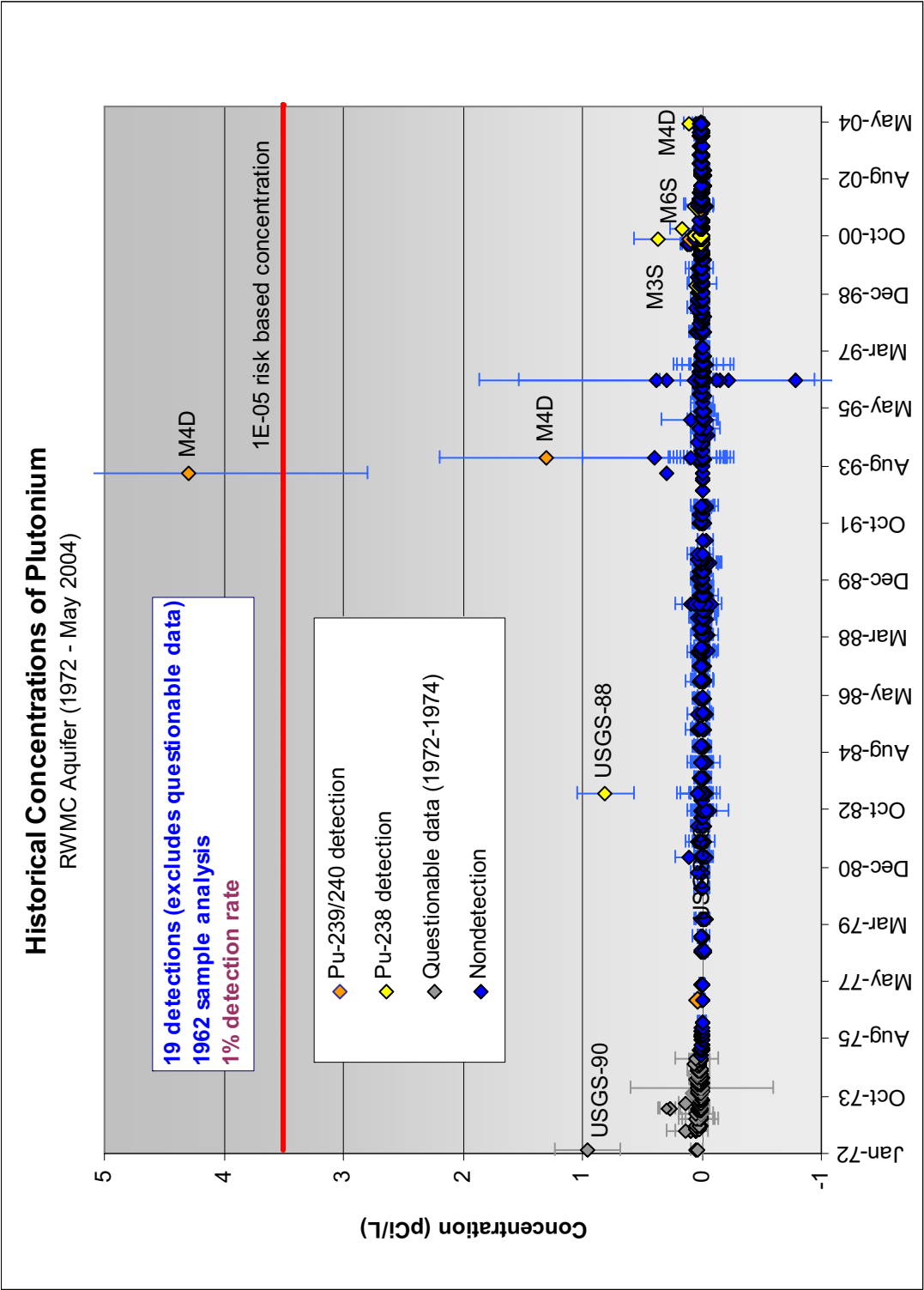


Figure 4-52. Plutonium concentrations in aquifer samples from 1972 to 2004.

Table 4-46. Concentration ranges and detection frequencies of plutonium-238 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Surface soil	2.0	7/356	0	NA	0.0044 ± 0.0014	—	0.032 ± 0.005 pCi/g
Surface vegetation	0.6	1/162	0	NA	NA	NA	0.0006 ± 0.0002 pCi/g
Surface run-off	0.0	0/237	0	NA	NA	NA	pCi/L
Vadose zone (0 to 35 ft)							
Cores	6.1	2/33	0	None	0.015 ± 0.002	0.137 ± 0.011	0.26 ± 0.02 pCi/g
Soil moisture	4.6	7/152	1	PA03	0.9 ± 0.3	6.7 ± 1.1	24 ± 2 pCi/L
Vadose zone (35 to 140 ft)							
Cores	7.5	11/146	0	None	0.0031 ± 0.0010	0.009 ± 0.002	0.017 ± 0.002 pCi/g
Soil moisture	2.6	3/116	0	None	3.1 ± 0.7	6.0 ± 1.0	11.6 ± 1.8 pCi/L
Vadose zone (140 to 250 ft)							
Cores	3.0	5/169	0	None	0.0015 ± 0.0004	0.0092 ± 0.0011	0.032 ± 0.002 pCi/g
Soil moisture and perched water	1.6	2/128 <sup>c</sup>	0	None	0.39 ± 0.05	2.6 ± 0.5	4.8 ± 1.0 pCi/L
Vadose zone (>250 ft)							
Cores	0.0	0/6	0	None	NA	NA	NA pCi/g
Soil moisture	0.0	0/13	0	None	NA	NA	NA pCi/L
Aquifer <sup>d</sup>	1.6	14/877	0	None	0.018 ± 0.006	0.13 ± 0.02	0.81 ± 0.08 pCi/L
Aquifer field blanks	2.4	1/41	0	None	NA	NA	0.084 ± 0.019 pCi/L

Note: Some reported results for Pu-238 could be false positives (see caveat in Section 4.13).

a. Ratio = number of detections/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. In addition to the 128 soil-moisture samples, 12 filtered sediment samples from perched Well USGS-92 also were analyzed, with one detection.

d. Questionable U.S. Geological Survey data from 1972 to 1974 are not included (see Section 4.1.6.4).

Table 4-47. Concentration ranges and detection frequencies of plutonium-239/240 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum Units
Surface soil	21.9	78/356	0	NA	0.0047 ± 0.0014	—	1.22 ± 0.12 pCi/g
Surface vegetation	9.2	15/162	0	NA	0.00046 ± 0.00016	—	0.024 ± 0.003 pCi/g
Surface run-off	3.8	9/237	0	NA	0.020 ± 0.006	—	0.11 ± 0.03 pCi/L
Vadose zone (0 to 35 ft)							
Cores	8.1	3/37	0	None	0.026 ± 0.005	0.47 ± 0.02	1.13 ± 0.05 pCi/g
Soil moisture	0.7	1/153	0	None	NA	NA	0.70 ± 0.17 pCi/L
Vadose zone (35 to 140 ft)							
Cores	13.7	21/153	0	None	0.009 ± 0.003	0.178 ± 0.010	0.74 ± 0.04 pCi/g
Soil moisture	2.6	3/116	0	None	0.34 ± 0.09	1.6 ± 0.5	3.3 ± 1.0 pCi/L
Vadose zone (140 to 250 ft)							
Cores	2.4	4/169	0	None	0.029 ± 0.004	0.092 ± 0.005	0.140 ± 0.007 pCi/g
Soil moisture and perched water	0.8	1/131 <sup>c</sup>	0	None	NA	NA	0.031 ± 0.013 pCi/L
Vadose zone (>250 ft)							
Cores	16.7 <sup>d</sup>	1/6	0	None	NA	NA	0.022 ± 0.003 pCi/g
Soil moisture	0.0	0/13	0	None	NA	NA	NA pCi/L
Aquifer <sup>e</sup>	0.6	5/876	1	M4D	0.034 ± 0.010	1.15 ± 0.17	4.3 ± 0.5 pCi/L
Aquifer field blanks	0.0	0/41	0	None	NA	NA	NA pCi/L

a. Ratio = number of detections/number of sample analyses.

b. Comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water) are provided in Table 4-1.

c. In addition to the 131 soil-moisture samples, 11 filtered sediment samples from perched Well USGS-92 also were analyzed, with one detection.

d. Detection frequency may be misleading because the sample set is too small (six samples) to provide statistical significance or meaning.

e. Questionable U.S. Geological Survey data from 1972 to 1974 are not included (see Section 4.1.6.4).

**4.13.6.4 Aquifer.** Current analytical evidence indicates that plutonium is not present at measurable concentrations in the aquifer around RWMC. This conclusion is based on results of analyses showing that ultra-low levels of plutonium are not present in the aquifer at the INL Site or RWMC (see Section 4.13.5). The conclusion that plutonium does not exist at measurable concentrations in the aquifer near RWMC also takes into consideration more than 800 plutonium results from USGS monitoring since 1975.

Figure 4-52 shows that detections are sporadic and random. Some results are likely to be false-positive detections; none can be attributed to transport from the SDA. Extensive monitoring of the aquifer for plutonium has been ongoing since 1972, with a network of 22 monitoring wells (as of May 2004) around RWMC. Almost 2,000 routine plutonium sample analyses have been performed during this time. The detection frequency of plutonium (Pu-238 + Pu-239/240) in the RWMC aquifer since 1972 is 1.9%; this is probably statistical noise because the frequency is comparable to the 1.8% detection rate observed in field blank samples. The detection frequency is reduced to 1.0% if questionable detections from 1972 to 1974 are excluded. As shown in Figure 4-52, some detections exhibit concentrations well above the noise range; however, in all cases, detections were not confirmed on reanalysis, analysis of a duplicate sample, or subsequent sampling events.

In addition to routine monitoring data, the conclusion that plutonium was not detected in the SDA is predicated on findings from various studies. Aquifer background studies based on isotope dilution-thermal ionization mass spectrometry and special sample preparation techniques (Roback 2003a, 2003b) did not detect plutonium in aquifer samples even though detection levels were 1,000 times lower than those provided by routine radiological methods (see Sections 4.13.5.1 and 4.13.5.2).

## 4.14 Radium-226 and Radium-228

Radium-226 is a radioactive decay product in the naturally occurring uranium series (see Section 4.1.2.2 and Figure 4-13). Radium-226 decays by the emission of alpha particles and gamma rays and has a half-life of 1,600 years. Radium-226 concentrations produced from Pu-238 (the initiating parent with a half-life of 87.7 years) would be extremely low because of the long half-lives of the intermediate progeny (i.e., U-234 and Th-230, with half-lives of  $2.46\text{E}+05$  and  $7.54\text{E}+04$  years, respectively). After 1,000 years, accounting for both decay of original inventories and ingrowth from members of the uranium series, approximately 42 Ci of Ra-226 would be present. Figure 4-13 illustrates the densities of Ra-226 in buried waste in the SDA. The total curies shown in Figure 4-13 include all Ra-226 that would be created through decay of all isotopes in the uranium decay chain. As noted above, much of this inventory is not created for millions of years, but is shown in the figure to identify all current and future sources of Ra-226.

Although Ra-226 was previously a targeted analyte, it was removed from the aquifer and vadose zone target analyte lists at the beginning of FY 2003 and 2004, respectively. Samples are gamma-scanned, and the analytical laboratory reports detections if Ra-226 is positively detected at concentrations greater than instrument and sample matrix background levels. No quantities of Ra-226 have been reported.

Radium-228 is a radioactive decay product in the naturally occurring thorium series (see Section 4.1.2.2 and Figure 4-18). Radium-228 decays by emission of beta particles and has a half-life of only 5.76 years. Waste buried in the SDA did not contain Ra-228 at the time of disposal; however, Ra-228 inventories will increase over time through ingrowth attributable to isotopes in the thorium series (see Figure 4-30). Ingrowth will be slow, however, because of the long half-lives of predecessor progeny (i.e., Pu-240, Th-232, and U-236, with half-lives of  $6.56\text{E}+03$ ,  $1.405\text{E}+10$ , and  $2.342\text{E}+07$  years, respectively). After 1,000 years, approximately 3.48 Ci of Ra-228 would be present. Because the inventory is primarily due to ingrowth, a density map is not provided for Ra-228; however, Figures 4-12, 4-18, and 4-22 illustrate the densities of Ra-228 predecessors. No monitoring data are available for Ra-228 because it is not a target analyte.

### 4.14.1 Waste Zone

About 65.1 Ci of Ra-226 was buried in the SDA (through 1999). An additional 0.19 Ci of Ra-226 is projected to be added by 2009, for a total of 65.3 Ci of Ra-226. Table 4-4 identifies waste streams containing Ra-226. The small inventories of Ra-226 in buried waste at the time of disposal are relatively insignificant. Radium-226 was identified as a contaminant of potential concern because additional quantities are being generated over time through ingrowth. Predecessor radioisotopes in buried waste include Pu-238 and U-234. These two isotopes are specifically addressed in this report (see Sections 4.13 and 4.18).

### 4.14.2 Vadose Zone

Distributions of Ra-226 in vadose zone core, soil moisture, and perched water in various depth intervals are discussed in the following subsections.

Vadose zone core data were compared against one of two surface soil background concentrations, depending on the analytical method used to obtain the result. Vadose zone core samples analyzed between 1971 and 1993 were quantified by measuring gamma rays of the equilibrated Ra-226 daughters. Therefore, the 1971 to 1993 Ra-226 data were compared to a background of 1.2 pCi/g. Results from the 1999 and 2000 analyses were obtained by gamma spectrometry methods, either by measuring the Ra-226

gamma ray without adjusting for U-235 interference or by measuring the gamma rays of its daughters without allowing time for their equilibration. In either case, the 2.2-pCi/g background value was used for comparison.

Radium-226 from lysimeter samples was analyzed by gamma spectrometry analysis, and the detection limits vary from about 25 pCi/L for an 80-mL sample to 1,000 pCi/L for a 25-mL sample. When larger sample volumes are available, a lower detection limit is achievable, but low concentrations equivalent to the MCL of 5 pCi/L (used for comparison) cannot be detected.

**4.14.2.1 Vadose Zone Core Samples.** Between 1971 and 2000, 109 vadose zone core samples were analyzed for Ra-226. Seventeen samples from 11 cores yielded Ra-226 concentrations greater than the background concentration for surface soil. All samples with relatively high Ra-226 were from the interbed sediment. Table 4-50 lists sample concentration ranges, detection frequencies, and exceedances. Core samples collected in FY 2004 were not targeted for Ra-226 analyses; therefore, results are not available. However, if Ra-226 daughter concentrations in the FY 2004 core samples were above instrument or sample matrix background, they would have been detected and reported during the gamma analysis of other targeted gamma-emitting radionuclides. Core samples collected between May 1999 and 2000 were analyzed for Ra-226 either by measuring the 186-keV gamma ray without compensating for an identical and interfering gamma ray from natural U-235 in soil or by measuring gamma rays of Ra-226 daughters without allowing time for their ingrowth and equilibration. For soil samples, Ra-226 results obtained by direct gamma spectrometry, without a specific analysis for Ra-226 that allows time for ingrowth of the Ra-226 daughters and measurement of the daughter gamma rays, are generally twice as high as they should be.

**4.14.2.2 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1997 and October 2003, 147 Ra-226 analyses were performed on soil-moisture samples collected from 18 shallow lysimeters near RWMC, with eight (5.4%) detections (see Table 4-50). The detections exceed the MCL for the aquifer used for comparison, and their occurrence relative to the other shallow lysimeter sampling events is shown in Table 4-48. Samples collected after October 2003 were not specifically analyzed for Ra-226; however, samples were analyzed by gamma spectrometry, and no Ra-226 results were reported above laboratory instrument or sample matrix background.

**4.14.2.3 Lysimeter Samples at Depths of 35 to 140 ft.** Between June 1997 and October 2003, 104 Ra-226 analyses were performed on soil-moisture samples collected from 14 shallow lysimeters near RWMC, yielding one detection. Samples collected after October 2003 were not specifically analyzed for Ra-226; however, samples were analyzed by gamma spectrometry, and no Ra-226 results were reported above laboratory instrument or sample matrix background.

**4.14.2.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between 1997 and October 2003, 73 Ra-226 analyses were performed on soil moisture and filtered sediment samples collected from 13 lysimeters and three perched water wells, with one positive detection. Filtered sediment samples showed some indication of positive Ra-226, but the detections are likely from presence of natural Ra-226 and U-235. Samples collected after October 2003 were not specifically analyzed for Ra-226; however, the samples were analyzed by gamma spectrometry, and no Ra-226 results were reported above instrument or sample matrix background.

The USGS does not analyze samples from perched water Well USGS-92 for Ra-226.



Table 4-48. Radium-226 detections in shallow (less than 35 ft) lysimeters since 1997.

Radium-226 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)														
Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01- L15	PA02- L16	PA03- L33	W06- L27	W08- L13	W08- L14	W23- L07	W23- L08	W23- L09	W25- L28
1997	1													
	2													
	3													
	4													
1998	1													
	2													
	3													
	4													
1999	1													
	2													
	3													
	4													
2000	1													
	2													
	3				34									
	4													
2001	1													
	2			46										
	3													
	4													
2002	1													
	2													
	3				50						47			
	4		73											
2003	1													
	2													
	3													
	4													
Note: The highest result is reported for duplicate samples or reanalysis.														
For comparison, maximum contaminant level = 5 pCi/L.														
	Ra-226 was analyzed but not detected.													
	Ra-226 was detected (pCi/L).													

#### 4.14.3 Aquifer

Between 1996 and November 2002, 286 analyses for Ra-226 analyses were performed on aquifer samples collected from 16 RWMC aquifer monitoring wells, with two detections (see Table 4-49). The detections exceed the MCL of 5 pCi/L. Table 4-49 shows when samples were taken from each of the 16 wells and when Ra-226 was detected. The two sample results that exceeded the MCL are questionable because the results are very near the method detection limit and barely exceeded the  $3\sigma$  detection criterion. Also, the results were obtained by gamma spectrometry analysis without allowing time for ingrowth of daughters and equilibration with the parent before sample counting. Samples collected after November 2002 were not specifically targeted for Ra-226 analysis; however, the samples were scanned for gamma-emitting radionuclides; if detected above background, Ra-226 would have been reported with the gamma analysis data. No Ra-226 results were reported above laboratory instrument or sample matrix background. All sample results for Ra-226 were obtained by direct gamma spectrometry analysis, which provides an adequate screening analysis but is not suitable for purposes of drinking water compliance.

The USGS does not analyze for Ra-226 in the eight RWMC wells it manages, controls, and routinely samples.

Table 4-49. Radium-226 detections in aquifer wells since 1996.

Radium-226 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	OW-2	A11 A31	USGS- 127
1996	1																
	2																
	3																
	4																
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																
2000	1																
	2																
	3																
	4																

Table 4-49. (continued).

Radium-226 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	OW-2	A11 A31	USGS- 127
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4			7.5													13
Note: The highest result is reported for duplicate samples or reanalysis.																	
For comparison, maximum contaminant level = 5 pCi/L.																	
		Ra-226 was analyzed but not detected.															
		Ra-226 was detected (pCi/L).															
		Well is out of service. Well was rendered inoperable after repairs were unsuccessful.															

#### 4.14.4 Summary of Radium-226

Vadose zone core samples were collected inside and outside the SDA. Results from cores outside the SDA were near background concentrations. Cores taken from the B-C and C-D interbeds inside the SDA contained Ra-226 concentrations greater than the background value of about 1 pCi/g. The samples did not contain elevated U-235, which is known to interfere with Ra-226 results. Some monitoring locations where Ra-226 was detected above background also contained Tc-99 and slightly elevated concentrations of U-235 (i.e., Lysimeter Wells I1S, I2S, I-3D, and I4D), compared to U-235 concentrations found at lysimeter locations outside the SDA. Elevated Ra-226 concentrations may be from U-235 interferences; however, enough analytical data are not available to make a confident determination.

Lysimeter and groundwater sample results do not corroborate Ra-226 presence in vadose zone core material. Of more than 320 lysimeter samples, Ra-226 was detected only 10 times, mostly from the 0 to 11-m (0 to 35-ft) interval, with two detections in the deeper lysimeter or perched water wells. Of the 286 groundwater samples, Ra-226 was detected two times. One of the detections was about 8 km (5 mi) east of RWMC (USGS-127), and the other was 0.8 to 1.6 km (0.5 to 1 mi) south (M4D). Table 4-50 lists detection rates for Ra-226.

Table 4-50. Concentration ranges and detection frequencies of radium-226 greater than background levels for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations			Units
					Minimum	Mean	Maximum	
Vadose zone (0 to 35 ft)								
Cores	7.7	1/13	0	None	NA	NA	1.7 ± 0.3	pCi/g
Soil moisture	5.4	8/147	8	98-4, 98-5, PA01, W06, W08, W23	33 ± 9	52 ± 13	73 ± 20	pCi/L
Vadose zone (35 to 140 ft)								
Cores	14.5	8/55	0	None	2.10 ± 0.06	5.3 ± 1.2	8 ± 2	pCi/g
Soil moisture	1.0	1/104	1	I-3S	NA	NA	2020 ± 607	pCi/L
Vadose zone (140 to 250 ft)								
Cores	21.6	8/37	0	None	2.60 ± 0.06	5.6 ± 1.2	7.9 ± 1.6	pCi/g
Soil moisture and perched water	0.0	1/69	1	USGS-92	NA	NA	43 ± 10	pCi/L
Vadose zone (>250 ft)								
Cores	0.0	0/4	0	None	NA	NA	NA	pCi/g
Soil moisture	0.0	0/4	0	None	NA	NA	NA	pCi/L
Aquifer	0.7	2/286	2	M4D, USGS-127	8 ± 2	10 ± 3	13 ± 4	pCi/L

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Table 4-1 provides comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water).

a. Ratio = number of detections above background concentrations/number of sample analyses.

b. Table 4-1 provides comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water).

## 4.15 Strontium-90

Strontium-90 is a radioisotope that is generated by nuclear reactor operations. Strontium-90 is a fission product that decays by the emission of beta particles with a 28.8-year half-life.

Available information about Sr-90 monitoring data for all media is summarized in this section. Sampling data in this section were evaluated against the comparison concentrations in Table 4-1. No waste zone spectral logging data are available for Sr-90 because Sr-90 is a pure beta-emitting radionuclide and has no associated gamma. Waste zone soil-moisture samples also were not analyzed for Sr-90.

### 4.15.1 Waste Zone

Approximately  $1.36\text{E}+05$  Ci of Sr-90 was buried in the SDA (through 1999), and an additional  $1.09\text{E}+02$  Ci is projected to be added by 2009, for a total of  $1.36\text{E}+05$  Ci. Waste streams containing most Sr-90 activity are identified in Table 4-4. The primary source of Sr-90 in the SDA is INL Site reactor operations waste and subassembly hardware. Strontium-90 also is of interest to the ongoing LLW disposal operation in the SDA and has an action level of 8 pCi/L in the aquifer (Parsons, Seitz, and Keck 2005). Figure 4-14 illustrates Sr-90 densities.

### 4.15.2 Surface

Between 1994 and 2004, 95 soil samples from near RWMC were analyzed for Sr-90, with 53 positive detections. Detections ranged from  $(4.04 \pm 1.04)\text{E}-02$  pCi/g at the spreading areas in 2003 to  $1.56 \pm 0.12$  pCi/g outside the northern side of SDA in 1997. All detected soil concentrations are less than the soil RBC of 55 pCi/g used for comparison.

Between 1990 and 2004, 49 vegetation samples from RWMC and control locations were analyzed for Sr-90, yielding 27 positive detections. Detections ranged from  $(8.61 \pm 0.27)\text{E}-03$  pCi/g at RW 3 in 2000 to  $2.01 \pm 0.12$  pCi/g at RW 1 in 1998.

Between 1991 and 2004, 103 surface run-off water samples from RWMC and control locations were analyzed for Sr-90, yielding four positive detections. Positive results ranged from  $(4.05 \pm 1.17)\text{E}-01$  pCi/L at control sample Well T-12 in 1999 to  $16.2 \pm 1.2$  pCi/L at the SDA in 1997. The concentration measured in 1997 (i.e.,  $16.2 \pm 1.2$  pCi/L) exceeded the MCL of 8 pCi/L used for comparison.

### 4.15.3 Vadose Zone

The following subsections discuss distribution of Sr-90 in vadose zone cores, soil moisture, and perched water in the various depth intervals.

#### **4.15.3.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.**

Three samples (see Section 4.1.4.5) were analyzed for radionuclides, and Sr-90 was detected in all three samples. Concentrations were  $2.71 \pm 0.16$ ,  $3.9 \pm 0.2$ , and  $59.0 \pm 1.1$  pCi/g, with the highest concentration exceeding the soil RBC of 55 pCi/g used for comparison.

**4.15.3.2 Vadose Zone Core Samples.** Between 1971 and 2000, 352 vadose zone core samples analyzed for Sr-90 resulted in 24 positive detections. Twelve of the 24 detections were from the 1971 and 1972 timeframe associated with cross-contamination in the core sampling method (see Section 4.1.6.4) (Barraclough et al. 1976; DOE-ID 1983). Table 4-55 shows positive detections of Sr-90, detection rates, concentration ranges, and exceedances of vadose zone core samples.

Most Sr-90 results are approximately the same or less than the surficial soil upper background tolerance limit of 0.49 pCi/g, with the exception of a few core samples. Most of the cores exceeding upper tolerance limits are from the 1971 and 1972 data sets and are, therefore, questionable because coring and sampling techniques may have introduced contamination into the boreholes or samples. Other cores with concentrations above the background tolerance limit are 4E, 5E, and 8V located inside the SDA. Cores 4E and 5E are at shallow depths, and 8E is located in the intermediate-depth interval. All sample concentrations are less than the soil RBC of 55 pCi/g used for comparison.

All detections from cores located outside the SDA are questionable because they are from the early 1970s and may be compromised by cross-contamination. These data are from the same timeframe as results from Cores USGS-91, USGS-92, and USGS-93 inside the SDA, which also are in that questionable data set (see Section 4.1.6.4).

**4.15.3.3 Lysimeter Well Samples at Depths of 0 to 35 ft.** Between 1997 and May 2001, 73 analyses for Sr-90 were performed on soil-moisture samples collected from 13 shallow lysimeters near RWMC, resulting in seven positive detections (see Table 4-55). Two of the samples were above the MCL used for comparison. No soil-moisture samples have been collected for Sr-90 analysis since May 2001 because of other analytical priorities. Also, Sr-90 is not a priority analyte in the vadose zone.

Positive sample results were not confirmed by reanalysis of the original samples. The occurrence of positive detections relative to samples that had nondetectable Sr-90 is shown in Table 4-51. The 52-pCi/L result obtained in Well W06-L27 was not confirmed by reanalysis, and Sr-90 was not detected in that lysimeter in the five sampling events subsequent to that detection.

**4.15.3.4 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1997 and 2001, 14 analyses for Sr-90 were performed on soil-moisture samples collected from eight intermediate-depth lysimeters near RWMC, resulting in one positive detection (see Table 4-55). The detection could not be confirmed by reanalysis because of the limited sample volume available. No other positive detections of Sr-90 have occurred in any lysimeters or perched water wells from this depth range since sample collection began in 1997. Therefore, a figure showing occurrences is not presented.

**4.15.3.5 Perched Water Samples at Depths Greater Than 140 ft.** Between 1972 and January 2002, 42 analyses for Sr-90 were performed by INL and USGS on 10 filtered sediment samples and three perched water samples. The results included one positive detection, and that detection occurred in Well USGS-92 and exceeded the aquifer MCL of 8 pCi/L used for comparison (see Table 4-55). The detection was not confirmed by reanalysis of the original sample, and all subsequent samples collected from perched water Well USGS-92 have not tested positive for Sr-90. No other positive detections of Sr-90 have occurred in any lysimeters or perched water wells from this depth range since sample collection began in 1997. Therefore, a figure showing occurrences is not presented.

No data are available from lysimeters at depths greater than 140 ft because the volume of water collected was insufficient to perform the analysis.

Table 4-51. Strontium-90 detections in shallow (less than 35 ft) lysimeters from 1997 to 2001.

Strontium-90 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																	
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
Note: The highest result is reported for duplicate samples or reanalysis.																	
For comparison, maximum contaminant level = 8 pCi/L.																	
		Analysis was performed, but Sr-90 was not detected.															
		Sr-90 was detected (pCi/L).															

#### 4.15.4 Aquifer

Between 1992 and May 2004, 476 analyses for Sr-90 were performed on samples from 16 RWMC aquifer monitoring wells using gross beta screening analysis, resulting in 128 of the sample results above the gross beta screening limit of 5 pCi/L. Those 128 samples were analyzed specifically for Sr-90 and, with duplicates and reanalysis, generated 144 analysis results, with three containing detectable amounts of Sr-90 (Table 4-55). No Sr-90 has been detected in RWMC aquifer samples since then (April 1997). Therefore, a figure showing occurrences is not presented.

Table 4-52 lists distributions of Sr-90 detections and nondetections in the aquifer between 1992 and 2004 for INL Site wells.

Table 4-52. Strontium-90 detections in aquifer wells from 1992 through 2004.

Strontium-90 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11 A31	OW-2	USGS-127 <sup>a</sup>
1992	1																
	2																
	3																
	4																
1993	1																
	2																
	3																
	4																
1994	1																
	2																
	3																
	4																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3				2.5												
	4																
1997	1																
	2																
	3			0.17													
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																



Table 4-52. (continued).

Strontium-90 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11 A31	OW-2	USGS-127 <sup>a</sup>
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis.																	
For comparison, maximum contaminant level = 8 pCi/L.																	
a. USGS-127 was transferred to the Idaho Cleanup Project and is no longer a U.S. Geological Survey well.																	
	Gross beta was analyzed but not detected above the trigger level of 5 pCi/L.																
	Strontium-90 was analyzed and detected (pCi/L).																

Between 1972 and April 2003, 699 analyses for Sr-90 performed on samples from eight USGS aquifer wells near RWMC resulted in 12 detections. Seven of the 12 detections occurred between 1973 and 1974 and are associated with potential cross-contamination (Barraclough et al. 1976) (see Section 4.1.6.4) (see Table 4-53). The five valid detections occurred between 1987 and 1995, and Sr-90 has not been detected in USGS monitoring wells since then.

Table 4-53 lists distributions of Sr-90 detections and nondetections in the aquifer from 1972 through 1992, and Table 4-54 provides results for USGS wells from 1993 through 2003.

Table 4-53. Strontium-90 detections in U.S. Geological Survey aquifer wells from 1972 through 1992.

Strontium-90 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1972	1								
	2								
	3								
	4								
1973	1		58						
	2								
	3		28						
	4	7							
1974	1								
	2	8	9		7				
	3	15							
	4								
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4								
1977	1								
	2								
	3								
	4								
1978	1								
	2								
	3								
	4								
1979	1								
	2								
	3								
	4								

Table 4-53. (continued).

Strontium-90 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1980	1								
	2								
	3								
	4								
1981	1								
	2								
	3								
	4								
1982	1								
	2								
	3								
	4								
1983	1								
	2								
	3								
	4								
1984	1								
	2								
	3								
	4								
1985	1								
	2								
	3								
	4								
1986	1								
	2								
	3								
	4								
1987	1								
	2								
	3	23							
	4								
1988	1								
	2								6.4
	3								
	4								

Table 4-53. (continued).

Strontium-90 U.S. Geological Survey Aquifer Monitoring Wells 1972 to 1992									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1989	1								
	2								
	3								
	4								
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								
1992	1								
	2								
	3								
	4								
Note: The highest result is reported for duplicate samples or reanalysis.									
For comparison, maximum contaminant level = 8 pCi/L.									
a. RWMC Production Well.									
	Strontium-90 was analyzed for but not detected.								
	Strontium-90 was detected (pCi/L).								
	Strontium-90 detections are questionable because of potential cross-contamination (see Section 4.1.6.4).								

Table 4-54. Strontium-90 detections in U.S. Geological Survey aquifer wells from 1993 through April 2003.

Strontium-90 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
1993	1								
	2								
	3								
	4								
1994	1								
	2								
	3								
	4								
1995	1								
	2								
	3								
	4								2.5
1996	1								
	2								
	3								
	4								
1997	1								
	2								
	3								
	4								
1998	1								
	2								
	3								
	4								
1999	1								
	2								
	3								
	4								
2000	1								
	2								
	3								
	4								

Table 4-54. (continued).

Strontium-90 U.S. Geological Survey Aquifer Monitoring Wells 1993 to 2003									
Calendar Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod <sup>a</sup>	USGS-117	USGS-119	USGS-120
2001	1								
	2								
	3								
	4								
2002	1								
	2								
	3								
	4								
2003	1								
	2								
Note: The highest result is reported for duplicate samples or reanalysis.									
For comparison, maximum contaminant level = 8 pCi/L.									
a. RWMC Production Well.									
		Strontium-90 was analyzed for but not detected.							
		Strontium-90 was detected (pCi/L).							

#### 4.15.5 Summary of Strontium-90

Data from samples from surface soil, vadose zone cores, lysimeters, perched water, and aquifer wells do not indicate the widespread presence of Sr-90 in the environment of RWMC at levels exceeding background concentrations. Strontium-90 detection rates, shown in Table 4-53, decrease with depth, from 9.6% in the shallow lysimeter wells to 1.1% in the aquifer wells. No trends are apparent. No spatial distribution pattern to the detections in the vadose zone or the aquifer wells is evident, and no detectable concentration of Sr-90 has been found in the aquifer wells since 1997. Lysimeter 98-1L35, the only lysimeter where Sr-90 has been detected more than once, is located at the southeastern corner of the SDA. The Sr-90 detections are sporadic and not indicative of emerging trends.

Table 4-55. Concentration ranges and detection frequencies of strontium-90 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Surface soil	14.9	53/356	0	NA	0.040 ± 0.010	—	1.56 ± 0.12 pCi/g
Surface vegetation	16.7	27/162	0	NA	0.0086 ± 0.0003	—	2.01 ± 0.12 pCi/g
Surface run-off	1.7	4/237	1	NA	0.41 ± 0.12	—	16.2 ± 1.2 pCi/L
Vadose zone (0 to 35 ft)							
Cores	15.2	7/46	0	None	0.13 ± 0.03	0.43 ± 0.07	0.92 ± 0.10 pCi/g
Soil moisture	9.6	7/73	2	PA02, W06	2.2 ± 0.7	11.1 ± 1.5	52 ± 4 pCi/L
Vadose zone (35 to 140 ft)							
Cores	5.4	8/148	0	None	0.19 ± 0.06	0.38 ± 0.08	0.69 ± 0.11 pCi/g
Soil moisture	7.1	1/14	0	None	NA	NA	4.1 ± 1.2 pCi/L
Vadose zone (140 to 250 ft)							
Cores	4.7	7/150	0	None	0.30 ± 0.09	0.57 ± 0.07	1.20 ± 0.10 pCi/g
Soil moisture	2.4	1/42 <sup>c</sup>	1	USGS-92	NA	NA	9 ± 2 pCi/L
Vadose zone (>250 ft)							
Cores	25.0 <sup>d</sup>	2/8	0	None	0.30 ± 0.09	0.35 ± 0.09	0.40 ± 0.09 pCi/g
Soil moisture	0.0	0/0	0	None	NA	NA	NA pCi/L
Aquifer <sup>e</sup>	1.1	8/735	2	USGS-87	0.12 ± 0.02	8.0 ± 1.4	23 ± 4 pCi/L
Aquifer field blanks	0.0	0/0	0	None	NA	NA	NA pCi/L

a. Ratio = number of detections/number of sample analyses.

b. Table 4-1 provides comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water).

c. In addition to the 42 soil-moisture and perched water samples, 10 filtered sediment samples from Perched Well USGS-92 were also analyzed with no detections.

d. The detection frequency at this depth interval is misleading because the sample set is too small (eight samples) to provide any statistical significance or meaning. Also, the two detections at this depth are the questionable 1971 and 1972 U.S. Geological Survey core data (see Section 4.1.6.4).

e. Questionable U.S. Geological Survey aquifer monitoring data from 1972 to 1974 are not included (see Section 4.1.6.4).

## 4.16 Technetium-99

Technetium-99 is a fission product generated primarily by nuclear reactor operations. It decays by emission of beta particles and low-energy gamma rays and has a half-life of  $2.13 \times 10^5$  years.

Technetium can be very mobile once released and has been detected in samples from vadose zone cores, lysimeters, perched water, and aquifer wells. This section summarizes Tc-99 monitoring data for all media. Sampling data in this section are evaluated against comparison concentrations in Table 4-1. No waste zone spectral gamma-logging data were available for Tc-99. Surface soil, vegetation, and run-off water samples also were not analyzed for Tc-99.

### 4.16.1 Waste Zone

Approximately 40.2 Ci of Tc-99 was buried in the SDA (through 1999), and an additional 2.09 Ci is projected to be added by 2009, for a total of 42.3 Ci. Waste streams containing most Tc-99 activity are identified in Table 4-4. The primary source of Tc-99 in the SDA is operations waste and subassembly hardware from INL reactors. Densities are illustrated in Figures 4-15 and 4-16.

**4.16.1.1 Waste Zone Lysimeter Samples.** Waste zone soil-moisture samples are not analyzed for Tc-99; however, in December 2004, a waste zone sample from Lysimeter DU-14-L3, located in the Depleted Uranium Focus Area, was analyzed and found to contain no Tc-99.

### 4.16.2 Vadose Zone

The following subsections discuss distribution of Tc-99 in vadose zone cores, soil moisture, and perched water in the various depth intervals.

**4.16.2.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.** Three samples were analyzed (see Section 4.1.4.5) for radionuclides, and Tc-99 was detected in all three samples. Concentrations were  $3.7 \pm 0.2$ ,  $2.19 \pm 0.12$ , and  $33.4 \pm 1.7$  pCi/g, which are all less than the soil RBC of 1,036 pCi/g used for comparison.

**4.16.2.2 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1997 and August 2004, 142 analyses for Tc-99 performed on soil-moisture samples collected from 18 shallow lysimeters near RWMC resulted in 27 positive detections (see Table 4-60). Detected concentrations varied from 13 to 68 pCi/L and were below the MCL of 900 pCi/L used for comparison. Concentration trends are not evident in this depth interval. Most historical detections in the 0 to 35-ft region of the vadose zone are from lysimeter wells located around Pad A (i.e., Wells PA01, PA02, and PA03) and the western part of the SDA (i.e., Wells 98-4, 98-5, W23, and W25). Table 4-56 presents historical detections and nondetections of Tc-99 in the shallow vadose zone.



Table 4-56. Technetium-99 detections in shallow (less than 35 ft) lysimeters since 1997.

Technetium-99 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																			
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	LYS1 : L41	PA01 : L15	PA02 : L16	PA03 : L33	W05: L24	W05: L25	W06: L27	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																		
	2																		
	3																	17	
	4																	30	
1998	1																		
	2																		
	3																		
	4																15*	20	
1999	1						39*	13	36										
	2																		
	3																		
	4																		
2000	1								21										
	2								17									20	
	3	16		21			17						15				39	33	
	4						27												
2001	1																		
	2																		
	3																46		
	4																		
2002	1																		
	2																		
	3																		
	4																15*		
2003	1		28*	34*	22*											68*			25*
	2																		
	3																		
	4																	42	
2004	1			19															
	2																		
	3																	35*	
	4																		
Note: The highest result is reported for duplicate samples or reanalysis.																			
For comparison, maximum contaminant level = 900 pCi/L.																			
* = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.																			
		Analysis was performed, but Tc-99 was not detected.																	
		Tc-99 was detected (pCi/L.)																	

Because disposal records do not indicate significant quantities of Tc-99 on or near Pad A, analytical data showing Tc-99 beneath Pad A could infer that topographic features in the subsurface are channeling leachate toward the region beneath Pad A. Alternatively, trace amounts of Tc-99 in uranium waste on Pad A could be the source (ICP 2005).

Monitoring Well W23 contains three lysimeters at depths about 8, 12, and 19 ft, and Tc-99 has been detected at all three depths. Eight out of 11 results from Lysimeter W23-L09 (8 ft deep) contained detectable amounts of Tc-99. In 1998, 2000, and 2001, Tc-99 was detected at 12 ft (W23:L08), and in 2002, it was detected at 19 ft (W23:L07). The progression of detections at different depths over time suggests that migration in the vadose zone may be occurring. Also, migration of Tc-99 occurs at Lysimeters D06:DL02 (13.4 m [44 ft]) and D06:DL01 (27 m [88 ft]).

**4.16.2.3 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1996 and August 2004, 113 analyses for Tc-99 were performed on soil-moisture samples collected from 19 intermediate-depth lysimeters near RWMC, resulting in 20 positive detections (see Table 4-60). Detected concentrations varied from 6 to 1,480 pCi/L. Technetium-99 concentrations in Lysimeters D06:DL02 and O7:DL28 each exhibited a single high concentration. Such a sudden increase in Well O7 from nondetection to 1,480 pCi/L is unexpected and questionable because the well is about 0.4 km (0.25 mi) southwest of RWMC, and infiltration from the SDA usually flows to the east to southeast because the interbeds generally slope in that direction. Subsequent samples collected from this well had no positive Tc-99 detections. Most historical detections in the 11 to 43-m (35 to 140-ft) region of the vadose zone are from lysimeter wells located around Pad A (i.e., Lysimeter D06) and the western part of the SDA (i.e., Lysimeters I1S, I2S, I3S, and D15). Historical detections in lysimeter samples from this depth range are depicted in Table 4-57.

Table 4-57. Technetium-99 detections in intermediate-depth (35 to 140 ft) lysimeters since 1996.

Technetium-99 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
1996	1														
	2														
	3			6											
	4														
1997	1														
	2														
	3														
	4														
1998	1														
	2														
	3														
	4	11	33												
1999	1			43*											20*
	2														
	3														
	4														

Table 4-57. (continued).

Technetium-99 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)															
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	TW1: DL04
2000	1														
	2														
	3			21											
	4														
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														
2003	1	13		28*	29*	25*	18*							20*	
	2														
	3	34													
	4	61													
2004	1	40			32									1480	22
	2														
	3	90	197												
	4														
Note: The highest result is reported for duplicate samples or reanalysis.															
For comparison, maximum contaminant level = 900 pCi/L.															
* = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.															
	Analysis was performed, but Tc-99 was not detected.														
	Tc-99 was detected (pCi/L).														

Because disposals records do not indicate significant quantities of Tc-99 on or near Pad A, analytical data showing Tc-99 beneath Pad A could infer that topographic features in the subsurface are channeling leachate toward the region beneath Pad A. Alternatively, trace amounts of Tc-99 in uranium waste on Pad A could be the source (ICP 2005).

Monitoring Well D06 contains two lysimeters at depths of 13.4 and 27 m (44 and 88 ft), and Tc-99 has been detected at both depths. At Lysimeter D06:DL01 (44 ft), the concentration has steadily decreased between 1998 and 2003; however, an unexplained concentration spike occurred in May 2004 (see Figure 4-53). The concentration at 88 ft (D06:DL02) has remained constant between 1998 and 2002. Then, in 2003, a trend began to develop, and the concentration has steadily increased since then (see Figure 4-53). The progression of detections and concentration changes over time at these two locations suggests that Tc-99 may be migrating in the vadose zone.

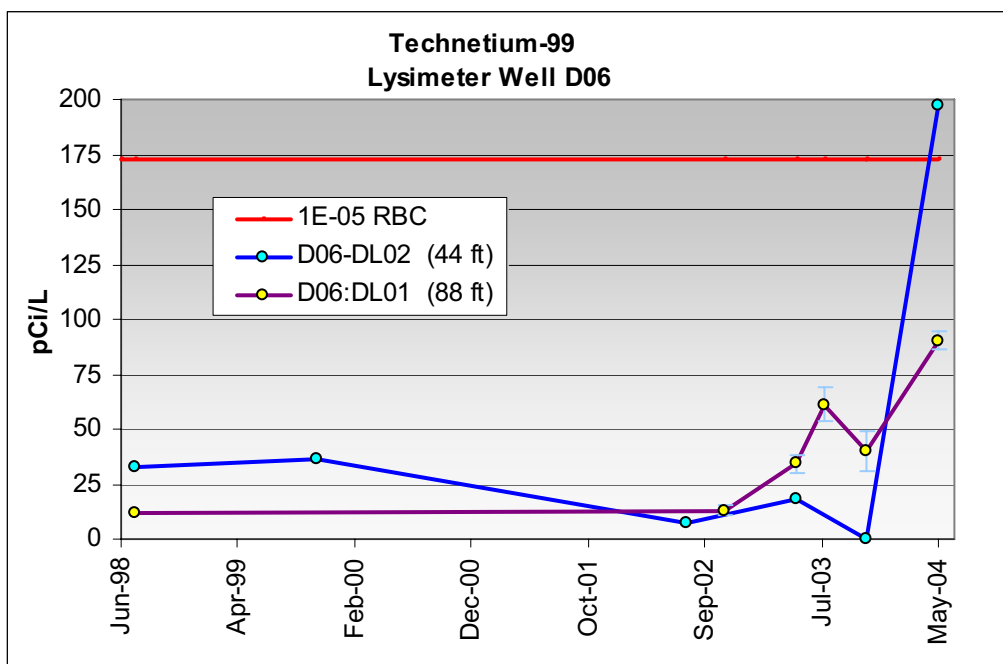


Figure 4-53. Technetium-99 concentration history for Lysimeters D06:DL01 and D06:DL02 showing possible migration from 44 to 88 ft starting in 2003.

**4.16.2.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Between 1996 and August 2004, 110 analyses for Tc-99 were performed on samples collected from 19 lysimeters and four perched water wells near RWMC, yielding 10 positive detections in water samples and two detections in filtered sediment samples (see Table 4-60). All detected concentrations were less than the MCL used for comparison. Historical detections in lysimeter and perched water samples in this depth range are depicted in Table 4-58.

Detecting Tc-99 in wells outside RWMC (i.e., Wells O2, O4, O6, and O7) in October 2002 was unexpected and could not be explained; however, there have been no detections in these outside wells since then. In fact, all lysimeters, other than Well USGS-92, have not had subsequent detections of Tc-99. No substantial evidence from soil moisture or perched water sample analyses shows that Tc-99 has moved to depths much beyond 140 ft. However, some core sample data indicate that Tc-99 may have reached the C-D (240 ft) interbed at several locations directly beneath the SDA (see discussion in Section 4.16.2.5).

The USGS does not analyze samples from perched water Well USGS-92 for Tc-99.

Table 4-58. Technetium-99 detections in deep (greater than 140 ft) lysimeters and perched water since 1996.

Technetium-99																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
1996	1																						
	2																						
	3																						
	4																						
1997	1																						
	2																						
	3																						
	4																						
1998	1																						
	2																						
	3																						
	4																						
1999	1																						28*
	2																						
	3																						
	4																						
2000	1																						
	2																						
	3																						
	4																						280

Table 4-58. (continued).

Technetium-99																							
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																							
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	S1898: DL40	TW1: DL03	USGS-092
2001	1																						
	2																						
	3																						
	4																						
2002	1																						
	2																						
	3																						
	4																						
2003	1														31		37	18*	29*				
	2																						
	3																						
	4																						28
2004	1				19									17									
	2																						
	3										41												
	4																						
Note: The highest result is reported for duplicate samples or reanalysis. For comparison, maximum contaminant level = 900 pCi/L (used for comparison). * = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.																							
	Analysis was performed for Tc-99, but none was detected.																						
	Tc-99 was detected (pCi/L).																						

**4.16.2.5 Vadose Zone Core Samples.** Between 1999 and 2004, 45 vadose zone core samples were analyzed for Tc-99, yielding 19 positive detections (see Table 4-60), with all concentrations less than the soil RBC of 1,036 pCi/g used for comparison. Core sample data for Tc-99 before 1999 do not exist because Tc-99 was not then a targeted radionuclide. All 19 detections were from samples collected in the B-C and C-D interbeds during the 1999-2000 drilling campaign to install vadose zone monitoring wells inside and outside the SDA. Only the “I” wells (inside the SDA) showed positive detections for Tc-99, with concentrations that ranged from about 1 to 4 pCi/g.

Fifteen of the 19 positive Tc-99 results from inside the SDA were qualified as questionable (J data qualifier flag) because Tc-99 also was detected in the laboratory method blank at about 0.3 pCi/g. The amount of Tc-99 in the method blank was small compared to actual sample concentrations; however, it does indicate a slight bias in the sample data (approximately 12% high) and also adds an element of uncertainty and questionability to the qualitative determination (i.e., is Tc-99 really present in these samples?).

Core samples collected outside the SDA contained no Tc-99. Though these samples were analyzed by a different laboratory than core samples collected inside the SDA, both laboratories used the same analytical methods, achieved similar detection sensitivities, and used comparable analytical quality control tests. The only difference in analytical methodology was the laboratory that detected Tc-99 used a sample mass of about 1 g for analysis, whereas the other laboratory used 6-g aliquots. Because the laboratory with the larger sample mass counted the samples for a shorter time interval, differences in sample mass probably did not affect detectability. The only other significant difference between the two data sets is that samples with nondetections (i.e., from outside the SDA) were older than 1 year, while samples with detections were newly acquired from fresh cores originating inside the SDA. Despite the small amount of Tc-99 in the method blank associated with detections, both sets of data from the laboratories appear to be valid.

More recent sampling (FY 2004) of archived cores collected November to December 2003 focused on the B-C and C-D sedimentary interbeds beneath the SDA to further investigate Tc-99 (Whitaker 2004). Thirteen interbed samples collected from inside the SDA and analyzed for Tc-99 resulted in no positive detections (Koeppen et al. 2005). Nondetections in the FY 2004 data set are inconsistent with 1999 to 2000 core investigation, which concluded that Tc-99 may be present in the B-C and C-D interbeds.

The Tc-99 detections in 1999 to 2000 were further evaluated to reconcile the discrepancy. Technetium-99 does not readily adsorb on sediment and does not partition to the vapor phase; it remains in the soil water. Using average bulk density ( $1.5 \text{ g/cm}^3$ ) and moisture content ( $0.3 \text{ cm}^3/\text{cm}^3$ ) of typical vadose zone soil and the maximum Tc-99 concentration measured in soil-moisture samples (280 pCi/L) at the SDA, the bulk sediment samples would have a concentration of about 0.06 pCi/g. Such a low concentration would not be detected because it is below the lower limits of detection for the method (less than or equal to 1 pCi/g). The calculated concentrations of Tc-99 in interbed sediment, based on the highest lysimeter concentration measured at the SDA, suggest that the 1999 and 2000 positive results could be erroneous. Alternatively, positive detections in 1999 and 2000 cannot be ruled out because Tc-99 (1) was buried in the SDA, (2) is highly mobile when in releasable waste forms, (3) was detected in multiple samples collected from the same cores in several wells in 1999 and 2000, (4) was detected in soil-moisture samples obtained from lysimeters placed near some of the coreholes, and (5) is predicted in model simulations, though not at the detected concentrations (see Section 5.2.5).

Different conclusions arising from each data set also may result from the differences in sample locations (see Figure 4-54) and the possibility that Tc-99 is present only in discrete locations, not widespread throughout the interbeds. Most core locations in FY 2004 do not correspond to locations sampled in 1999 to 2000. The only core locations that are near one another are DE4 (2004) and

I4D (2000) in the southwestern corner of Pad A; however, samples from these two cores at comparable depths yielded contradictory data. In 1999 to 2000, positive detections of Tc-99 occurred in all four sediment samples collected from Well I4D; whereas in 2004, no detections were observed in the two sediment samples obtained from nearby Well DE4.

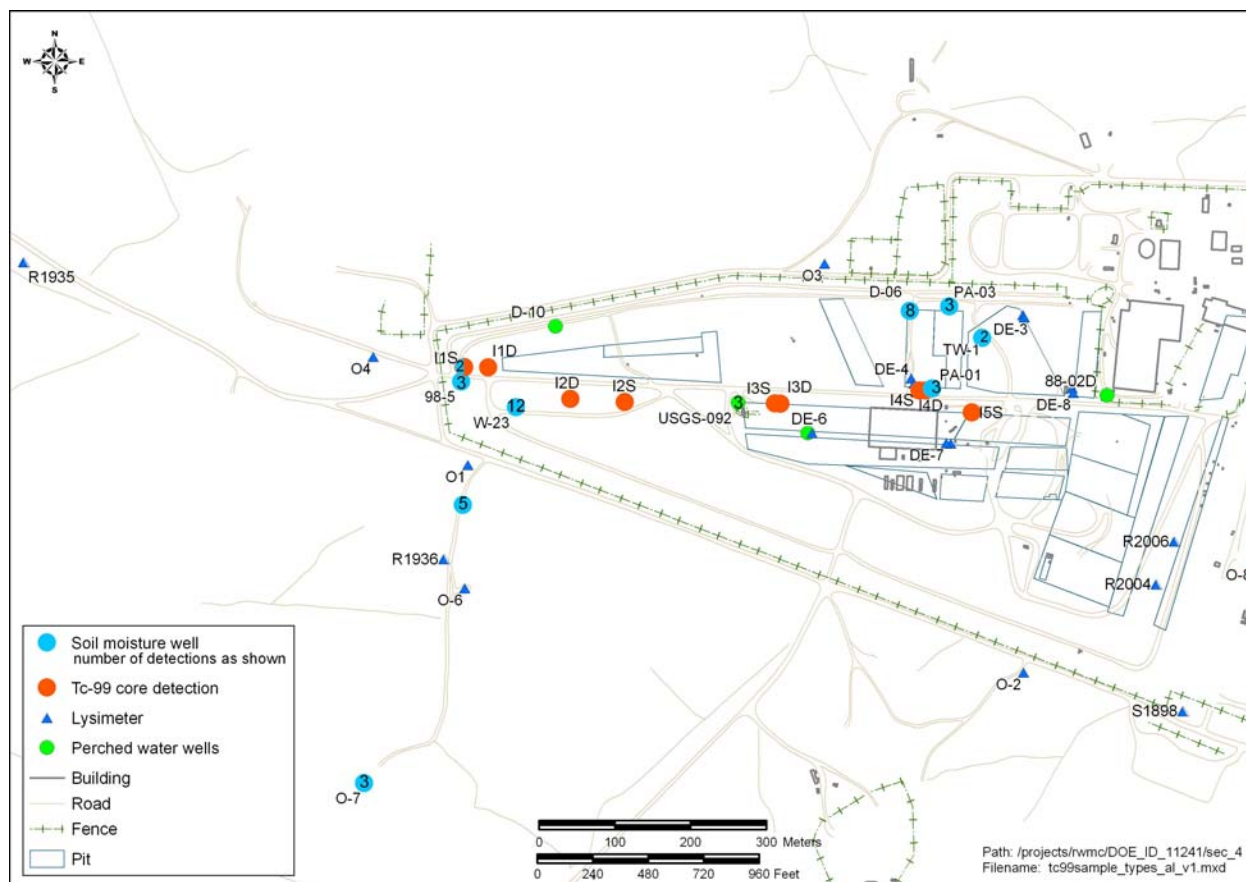


Figure 4-54. Technetium-99 results in core samples collected in 1999 to 2000 and 2003.

The core locations where Tc-99 was detected in 1999 to 2000 also were compared to lysimeter well locations where Tc-99 is detected (see Figure 4-55). Soil-moisture data correlate to core sample data for Tc-99; however, the correlation is not sound because it involves lysimeters where Tc-99 is only intermittently detected. Therefore, the relationship between soil moisture and core contamination does not provide adequate evidence to resolve questions about Tc-99 in the 1999 to 2000 cores.

A possible resolution to determine the presence or absence of Tc-99 in RWMC interbeds would be to resample the 1999 to 2000 interbed cores at the precise locations where positive detections of Tc-99 were originally observed and to have the core material analyzed at the laboratory that reported nondetections. Though reanalysis would reduce uncertainty regarding Tc-99 migration, it would not be likely to reverse the conclusion that migration is probably occurring.



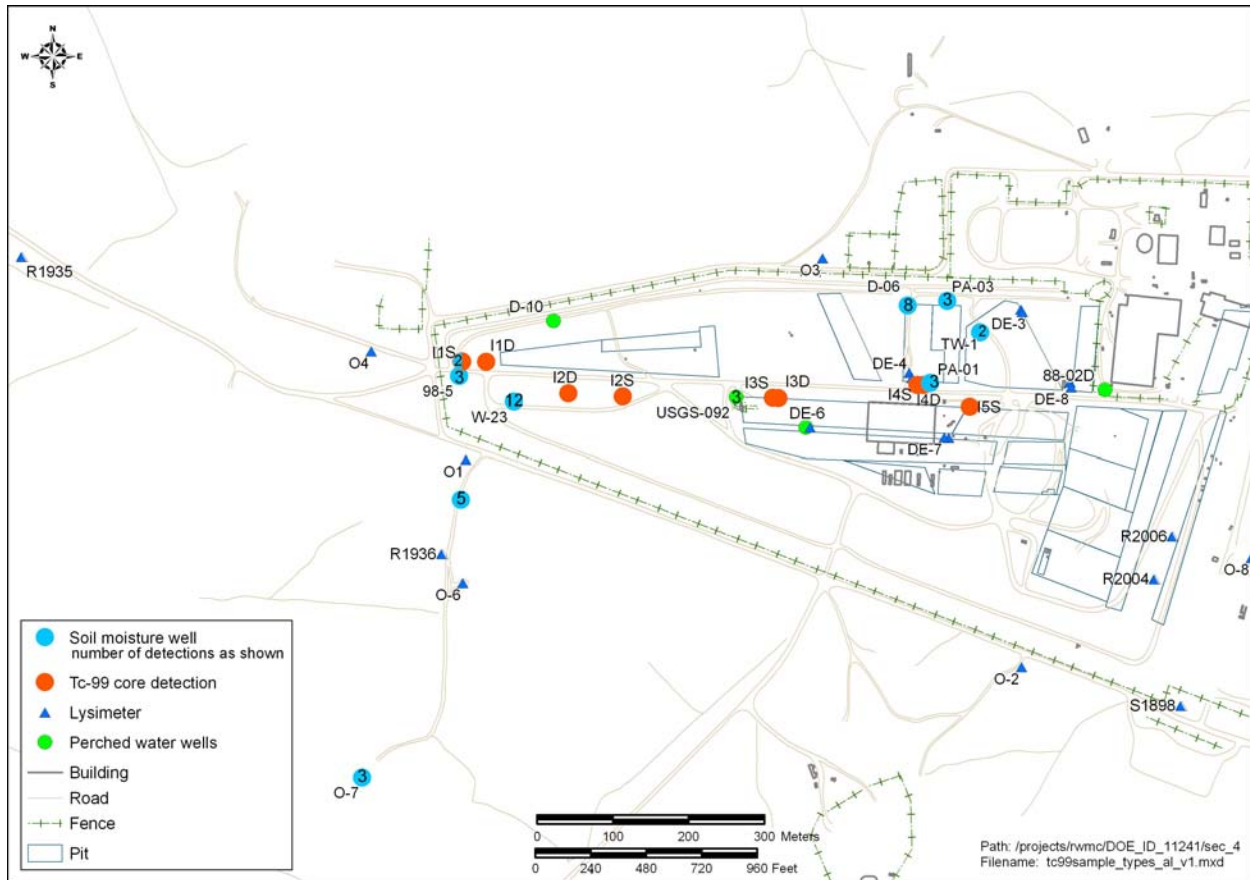


Figure 4-55. Core samples and soil moisture samples with technetium-99 detections.

#### 4.16.3 Aquifer

Between 1994 and May 2004, 432 analyses for Tc-99 performed on aquifer well samples from 16 monitoring wells near RWMC resulted in seven positive detections (see Table 4-60). None of the positive results exceeded the MCL of 900 pCi/L. Only the May 2000 detection of Tc-99 for Well M17S was confirmed by reanalysis of the original sample, but the positive result did not agree with the original analysis. As shown in Table 4-59, subsequent samples collected from the five aquifer wells have not yielded positive detections.

The USGS does not analyze for Tc-99 in the eight RWMC wells they manage, control, and routinely sample.

Table 4-59. Technetium-99 detections in aquifer wells since 1994.

Technetium-99 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
1994	1																
	2																
	3																
	4																
1995	1																
	2																
	3																
	4																
1996	1																
	2																
	3												9.0				
	4												7.4*				
1997	1																
	2																
	3											1.4		1.0			
	4																
1998	1																
	2																
	3																
	4																
1999	1																
	2																
	3																
	4																

Table 4-59. (continued).

Technetium-99																	
Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	A11A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
2000	1																
	2																
	3									35							
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2														1.2		
	3																
	4																
2003	1																
	2																
	3																
	4																
2004	1																
	2																
	3																
Note: The highest result is reported for duplicate samples or reanalysis.																	
For comparison, maximum contaminant level = 900 pCi/L.																	
* = indicates a positive detection that received a J qualifier flag because of a minor quality control anomaly.																	
	Analysis was performed, but Tc-99 was not detected.																
	Tc-99 was detected (pCi/L).																
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.																

#### 4.16.4 Summary of Technetium-99

Technetium-99 is frequently detected in soil-moisture samples collected in the 0 to 35-ft and 35 to 140-ft depth intervals and is intermittently detected in the 140 to 250-ft region. Soil-moisture concentrations generally range from about 6 to 200 pCi/L; however, one anomalous result reached 1,480 pCi/L. The disputed presence or absence of Tc-99 in RWMC I-series core samples in 1999 to 2000 has yet to be substantiated (see discussion in Section 4.16.2.5). Therefore, a possibility remains that Tc-99 has migrated to the B-C and C-D interbeds. Technetium-99 contamination in the vadose zone does not appear to be widespread, but rather appears more prevalent around Pad A, the western end of the SDA, and specific areas within the interbeds (see Figures 4-54 and 4-55).

Historically, lysimeter wells with the most frequent and consistent detections of Tc-99 are Lysimeter Wells D06 and W23 (see detection rate in Table 4-60). A concentration trend appears to be developing in Well D06 (see Figure 4-53). These wells are located in areas of the SDA where no Tc-99 disposals are noted. The only commonality between these two wells is that, in addition to the presence of Tc-99, uranium concentrations are elevated.

Historically, Tc-99 has not been a monitoring priority for limited sample volumes produced by lysimeters; however, since 2004, Tc-99 monitoring in the vadose zone has been assigned a higher priority. Monitoring capability is sparse in some areas where Tc-99 was buried.

Detections of Tc-99 occur sporadically in the aquifer and are not indicative of trends or widespread contamination.

Table 4-60. Detection frequencies for technetium-99 in sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations		
					Minimum	Mean	Maximum
Vadose zone (0 to 35 ft)							
Cores	NA	NA	NA	None	NA	NA	pCi/g
Soil moisture	19.0	27/142	0	None	13 ± 3	27 ± 5	68 ± 6 pCi/L
Vadose zone (35 to 140 ft)							
Cores	52.9	9/17	0	None	1.08 ± 0.17	2.5 ± 0.3	4.2 ± 0.4 pCi/g
Soil moisture	17.7	20/113	1	O7S	5.8 ± 1.3	111 ± 8	1480 ± 28 pCi/L
Vadose zone (140 to 250 ft)							
Cores	35.7	10/28	0	None	1.46 ± 0.19	2.5 ± 0.3	3.4 ± 0.3 pCi/g
Soil moisture and perched water	9.3	9/97	0	None	17 ± 5	57 ± 10	280 ± 37 pCi/L
Vadose zone (>250 ft)							
Cores	NA	NA	NA	None	NA	NA	pCi/g
Soil moisture	7.7	1/13	0	None	NA	NA	19 ± 5 pCi/L
Aquifer	1.6	7/432	0	None	1.0 ± 0.3	8.1 ± 1.3	35 ± 5 pCi/L
Aquifer field blanks	6.1	3/43	0	None	0.34 ± 0.10	2.1 ± 0.3	4.9 ± 0.5 pCi/L

a. Ratio = number of detections/number of sample analyses.

b. Table 4-1 provides comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water).

a. Ratio = number of detections/number of sample analyses.

b. Table 4-1 provides comparison concentrations (e.g., risk-based concentrations for soil and maximum contaminant levels for water).

## 4.17 Thorium-228

Thorium-228 is a radioactive decay product in the naturally occurring thorium series (see Section 4.1.2.2 and Figure 4-17). Waste buried in the SDA contained Th-228 at the time of disposal. Additional Th-228 inventories will be generated over time through ingrowth attributable to isotopes in the thorium decay series also contained in the SDA inventory at the time of disposal (i.e., Pu-240, U-236, and Ra-228). These predecessors are Pu-240 and U-232. After 1,000 years, approximately 3.5 Ci of Th-228 would be contributed from Pu-240, and approximately  $7.178\text{E-}04$  Ci of Th-228 would remain from U-232, though inventories earlier in time would range as high as 9 Ci. Total Th-228 from both sources at 1,000 years would be 3.5 Ci, nearly all from the Pu-240 decay chain. Other contaminants of potential concern associated with the thorium decay series include Pu-240 (see Section 4.13), U-236 (see Section 4.18), and Ra-228 (see Section 4.14). Thorium-228 has not been detected in the SDA because it has not been a targeted analyte. Thorium-228 decays by alpha emission and has a half-life of  $1.91\text{E+}01$  years. Densities of Th-228 and U-232 in buried waste are identified in Figures 4-17 and 4-23, respectively. See Figure 4-12, 4-22, and 4-18 for densities of other Th-228 predecessors.

## 4.18 Uranium-233, Uranium-234, Uranium-235, Uranium-236, and Uranium-238

Uranium is a radioactive element that occurs naturally in the environment, principally as U-238 with trace quantities of U-234 and U-235 (see Table 4-61). Uranium also is used in nuclear weapons and nuclear reactors. Waste generated by these activities typically contains four principal uranium isotopes: U-234, U-235, U-236, and U-238. A fifth uranium isotope in waste, U-233 is produced in small quantities from decay of Am-241 and in significant quantities in nuclear reactors that use thorium fuel. Uranium-233, U-234, U-235, U-236, and U-238 all decay by emitting alpha particles and gamma rays and have half-lives of 1.59E+05, 2.46E+05, 7.04E+08, 2.34E+07, and 4.47E+09 years, respectively. All four natural decay series (see Figures 4-20 through 4-23) include uranium isotopes: U-236 is in the thorium series, U-233 is in the neptunium series, both U-238 and U-234 are in the uranium series, and U-234 is in the actinium series.

Table 4-61. Properties of uranium isotopes.

Property	Uranium-233	Uranium-234	Uranium-235	Uranium -236	Uranium -238
Half-life (years)	1.59E+05	2.46E+05	7.04E+08	2.34E+07	4.47E+09
Specific activity (pCi/g of isotope)	9.65E+09	6.19E+09	2.13E+06	6.49E+07	3.36E+05
Activity in 1 g of natural uranium (pCi)	0	3.34E+05	1.54E+04	0	3.34E+05
Natural abundance (percent by weight)	0	0.0055	0.7200	0	99.2745
Natural abundance (activity percent)	0	48.87	2.25	0	48.87

Naturally occurring uranium coexists with anthropogenic sources in and near the SDA. To assess nature and extent of anthropogenic uranium contamination, background uranium in the environment must be differentiated from that introduced by waste disposal. The amount of uranium in the environment varies significantly around the globe, including Idaho and the INL Site. Background concentrations are established for U-234 and U-238 in surficial soil (Rood, Harris, and White 1996) and for total uranium in the Snake River Plain Aquifer (Knobel, Orr, and Cecil 1992). Background concentration upper limits for uranium isotopes in the aquifer at the INL Site and RWMC, using monitoring data from various sources including those from USGS, are established in Koeppen et al. (2005). These values are listed in Table 4-1.

Anthropogenic uranium can be discriminated from naturally occurring uranium by assessing isotopic ratios. Table 4-62 presents typical isotopic ratios in natural and anthropogenic materials. Table 4-63 lists common isotopic compositions associated with enriched, depleted, and natural uranium. Enriched uranium refers to uranium ore that has been processed to increase the concentration of U-235. Gaseous diffusion technology is most commonly used in the United States to remove U-238, which increases concentrations of both U-234 and U-235 (DOE-STD-1136-2004). The by-product of the enrichment process, which contains increased concentrations of U-238, is referred to as depleted uranium.

Table 4-62. Radioactivity ratios for evaluating uranium data.

Type of Uranium (weight percent of U-235 present)	U-234:U-238 Ratio	U-238:U-235 Ratio
Depleted (0.2)	~0.1	~78
Natural in earth's crust (0.7)	~1 <sup>a</sup>	~22
Natural in INL Site groundwater (0.7)	~1.5 to 3 <sup>b</sup>	~22
Low enrichment (3)	~6	~5
High enrichment (93)	~3,300	~0.01

Note: Ratios for depleted uranium and enriched uranium were obtained from the Rocky Flats Plant and "Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities" (DOE-STD-1136-2004).

a. Secular equilibrium conditions.

b. Disequilibrium—characteristic of INL Site groundwater and vadose zone soil moisture.

INL = Idaho National Laboratory

Table 4-63. Typical isotopic composition of anthropogenic uranium (weight percent).

Form	U-234 (%)	U-235 (%)	U-236 (%)	U-238 (%)
Enriched (high)	1.00	93.10	0.40	5.50
Enriched (low)	0.03	2.97	0.00	97.00
Depleted	0.001	0.22	0.00	99.78

Concentrations of uranium isotopes in monitoring samples generally are reported by the laboratory as U-233/234 (or U-233+234), U-235/236 (or U-235+236), and U-238. Pairs of isotopes are combined because they cannot be chemically separated, and they have alpha particle energies that are nearly identical. Therefore, uranium isotopes are almost impossible to differentiate in environmental-level samples using routine alpha spectroscopy. More sensitive, nonroutine analysis (i.e., mass spectrometry) is required to obtain results for each separate isotope or to determine accurate isotopic ratios. The following subsections describe methodology used to interpret uranium monitoring data at the SDA and summarize available uranium monitoring data for all media.

#### 4.18.1 Methodology for Interpreting Uranium Monitoring Data

Methodology for interpreting uranium monitoring data involves evaluating isotopic ratios and discriminating background concentrations from anthropogenic uranium. Recent changes to methodology for evaluating isotopic ratios and background concentrations are summarized in subsections that follow. Details will be available in the FY 2005 Annual Monitoring Report.

**4.18.1.1 Isotopic Uranium Ratios.** Activity ratios of U-238:U-235 and U-234:U-238 are used to distinguish natural uranium from anthropogenic uranium and to estimate the amount of U-235 enrichment in anthropogenic uranium. Historically detected U-238:U-235 ratios at some monitoring locations showed changes and trends interpreted as indicating the presence of anthropogenic uranium slightly enriched with U-235 (Olson et al. 2003; Koeppen et al. 2004; Koeppen et al. 2005). Trends in U-238:U-235 ratios were caused solely by changes in U-235 concentrations—that is, U-238 concentrations were relatively constant



while U-235 concentrations fluctuated. Though U-238:U-235 ratios were changing at these locations, U-234:U-238 ratios remained constant, which is unusual for anthropogenic uranium (see Table 4-63). Lack of correlation indicates that historical U-238:U-235 ratios are ambiguous; raising substantial doubt about previous conclusions that anthropogenic uranium was present. In response, the analytical and assessment process for evaluating isotopic uranium data was carefully reviewed, reaching the following conclusions about historical interpretations:

- Trends in U-238:U-235 isotopic ratios are not consistent with expected ratios and trends for U-234:U-238
- Inductively coupled plasma mass spectrometry analyses in November 2004 indicate previous assessments using U-238:U-235 activity ratios may be inaccurate
- Review of process indicators used to characterize low- and mid-level detections of uranium (i.e., measured concentrations, measurement uncertainties, isotopic ratios, background sample locations, and background concentration values) lack the robustness necessary for accurate characterization
- Activity ratios for U-238:U-235 obtained by routine analysis (alpha spectrometry) are inaccurate because of high uncertainties associated with low-level U-235 measurements
- All previous interpretations based on uranium activity ratios obtained by routine analysis should be discarded.

Uranium-235 is the most difficult uranium isotope to quantify accurately by alpha spectrometry because of its low activity in most environmental water samples (e.g., soil pore water, perched water, and aquifer samples). Historically, U-235 concentrations in most environmental water samples were too low to obtain reliable measurements using traditional radioanalytical methods (e.g., alpha spectrometry). Because routine monitoring requires isotopic uranium analysis using alpha spectrometry, U-235 and calculated U-238:U-235 activity ratios have relatively large uncertainties, especially at low concentrations. At locations in the SDA where uranium concentrations were high relative to other locations, U-238:U-235 activity ratios were used to tentatively identify the origin (i.e., natural or anthropogenic) and enrichment (i.e., if anthropogenic, whether from weapons production or reactor operations) of uranium.

In November 2004, samples from four wells previously suspected of containing anthropogenic uranium with a slight U-235 enrichment were analyzed by inductively coupled plasma mass spectrometry (Koeppen et al. 2006). Other than one sample location, inductively coupled plasma mass spectrometry results refuted conclusions formulated from historical alpha spectrometry measurements that anthropogenic uranium was present (Olson et al. 2003; Koeppen et al. 2004; Koeppen et al. 2005). Historical U-238:U-235 activity ratios suggested that uranium at these four locations was anthropogenic and slightly enriched in U-235. Results from analytical methods for U-234 and U-238 compared reasonably well; however, U-235 results did not (see Figures 4-56, 4-57, and 4-58). On both Figures 4-56 and 4-57 (i.e., U-234 and U-238 comparison analyses), the slope of the best-fit linear regression is near 1, with a y-intercept near zero, showing that correlation between inductively coupled plasma mass spectrometry and alpha spectrometry analyses is nearly 1:1, with very good agreement in results obtained using the two methods. However, the slope of the best-fit linear regression in Figure 4-57 (i.e., U-235 comparison analyses) is 1.8, indicating that U-235 measurements by alpha spectrometry are biased high compared to inductively coupled plasma mass spectrometry results. Removing the upper, nonlinear point improves correlation between the two analytical methods, but increases the slope of the best-fit linear regression to 1.98. Thus, removing the upper, nonlinear point actually increases bias in the measurements.

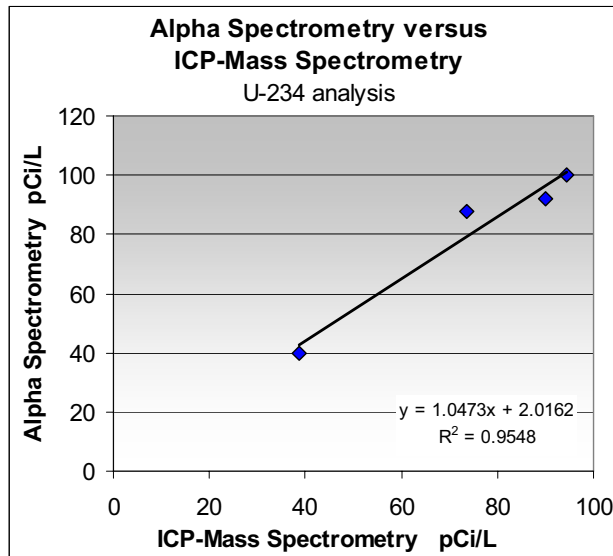


Figure 4-56. Reasonable agreement between alpha spectrometry and inductively coupled plasma mass spectrometry analysis of uranium-234.

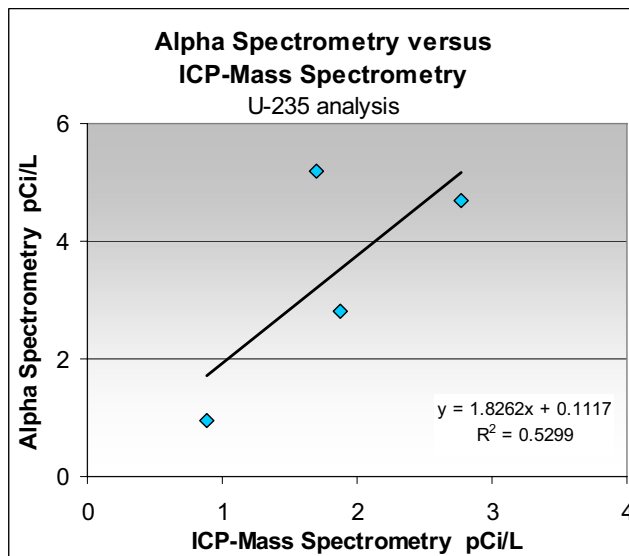


Figure 4-57. Poor agreement between alpha spectrometry and inductively coupled plasma mass spectrometry analysis of U-235.

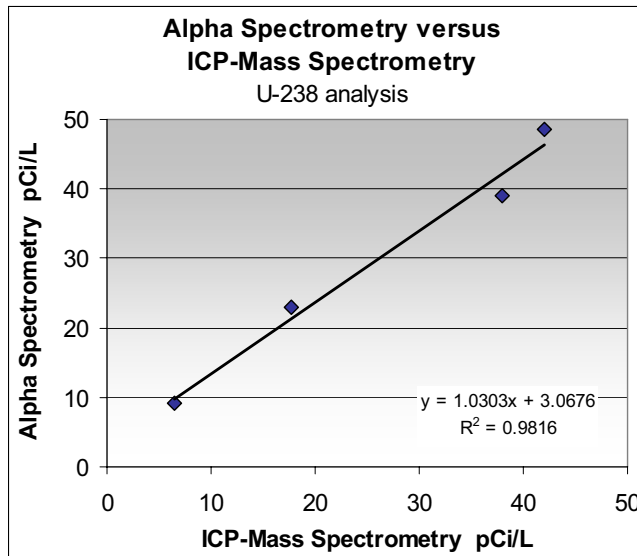


Figure 4-58. Reasonable agreement between alpha spectrometry and inductively coupled plasma mass spectrometry analysis of uranium-238.

Because U-238:U-235 activity ratios obtained by alpha spectrometry do not provide an accurate means for assessing the origin and enrichment of low-level uranium, alpha spectrometry results obtained in 1999 and 2000 were compared to isotope dilution thermal ionization mass spectrometry results obtained from an independent study (Roback et al. 2000). Compared RWMC soil-moisture samples were not part of the same sampling set, and sampling dates differ by 2 to 7 months. Nevertheless, notable bias is evident in ratios determined with alpha spectrometry measurements (i.e., high bias in low-level U-235 results) (see Figure 4-59). Activity ratios for U-234:U-238 from both analytical methods compare reasonably well, varying from 2 to 11%.

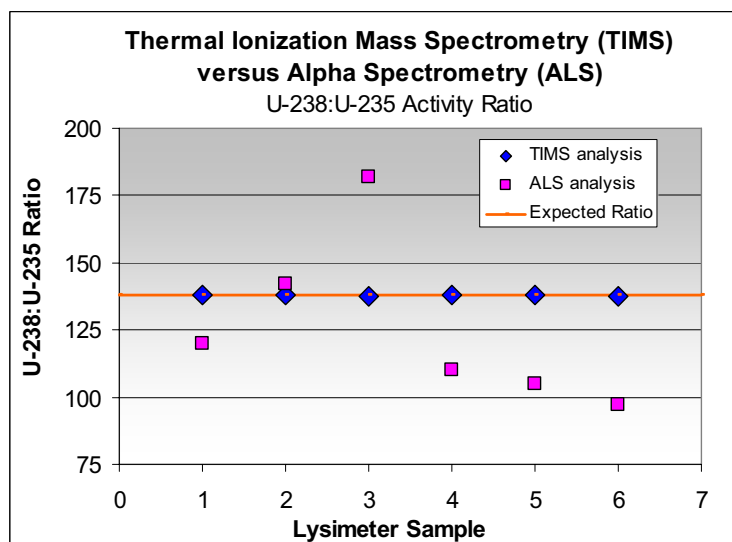


Figure 4-59. Comparison of U-238:U-235 activity ratios measured by isotope dilution thermal ionization mass spectrometry and alpha spectrometry in 1999 and 2000.

Because of the very large uncertainty and bias associated with low-level U-235 measurements by alpha spectroscopy, U-238:U-235 ratios were evaluated on aquifer background samples to determine whether the ratio pattern is similar to that observed in soil-moisture samples. The U-238:U-235 ratios show a similar pattern to that of the soil-moisture samples, indicating the historical conclusion—that anthropogenic uranium with a slight U-235 enrichment was present—was erroneous (see Figure 4-60). In the Roback et al. (2000) study, using thermal ionization mass spectrometry, soil-moisture samples with elevated uranium concentrations (up to 144 ppb) and aquifer samples were found to have natural U-238:U-235 isotope ratios, and no U-236 was detected. Most of these samples were interpreted as natural uranium. Therefore, U-238:U-235 ratios, which were solely used to determine the origin of elevated levels of uranium, are no longer regarded as appropriate for uranium assessment without also applying U-234:U-238 activity ratios. Nearly all aquifer samples show similarly enriched uranium values, corroborating the bias in U-235 measurements obtained with alpha spectrometry.

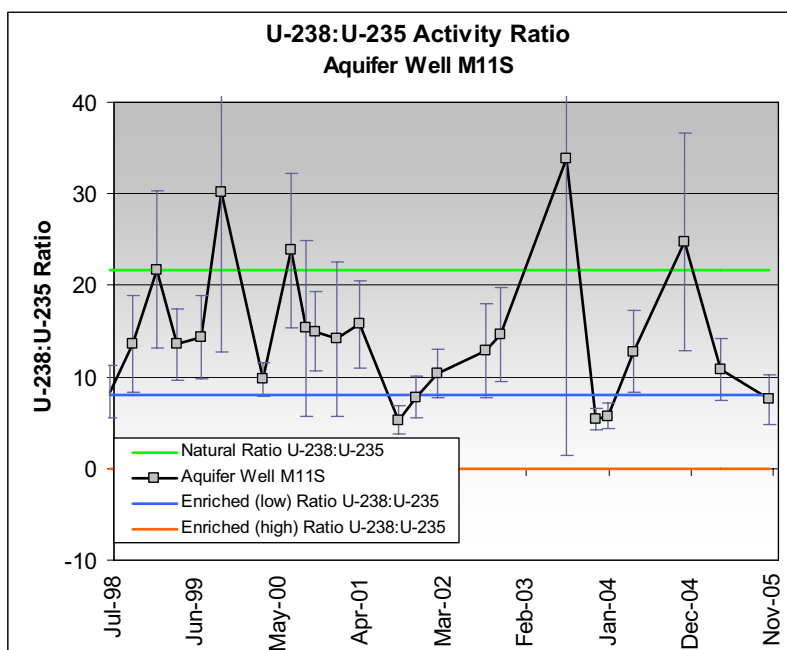


Figure 4-60. Aquifer background activity ratios for U-238:U-235 in Well M11S.

Using current information, all vadose zone lysimeter samples with detected and elevated concentrations of U-234, U-235, and U-238 were reassessed using both U-234:U-238 and U-238:U-235 activity ratios. As demonstrated in discussions of uranium monitoring data (see Sections 4.1.8.3, 4.1.8.4, 4.1.8.5, and 4.1.8.6), the correlation between those two activity ratios (i.e., U-234:U-238 and U-238:U-235) shows that all locations in the vadose zone and aquifer with elevated uranium concentrations are characteristic of natural uranium except Lysimeter TW1:DL04 beneath Pit 5 at a depth of 31 m (102 ft).

#### 4.18.1.2 Background Concentrations and Concentration Limits for Evaluating Uranium.

Methodology for determining upper background concentration limits for uranium in vadose zone soil-moisture samples was recently reviewed and refined (Koeppen et al. 2006). The historical conservative upper-limit value (i.e., mean concentration, plus one standard deviation of the mean) was replaced, beginning in FY 2005, with the maximum concentration of each uranium isotope observed in the background data set. This refinement was warranted because adequate background data sets have been accrued. Areas in the SDA with possible uranium abnormalities and areas characteristic of background were both observed and evaluated. Table 4-64 lists statistical characteristics of background concentrations

used to establish upper-limit values for uranium isotopes. The complete data set underlying the statistics is available in the FY 2005 Annual Monitoring Report (Koeppen et al. 2006). Note that maximum concentration values used for comparison are similar to the mean plus three times the standard deviation of the mean. Constraints on using or selecting a maximum concentration value require that the value (1) be an expected value, (2) be characteristic of variances typically observed, and (3) not be a statistical outlier. Local background levels for the vadose zone were established using data from lysimeters installed in the B-C and C-D interbeds located outside SDA boundaries. Values for interbed sediment may not be representative of alluvium at shallower depths, but were used for comparison only to interpret data from the A-B interbed (sediment from the surface to the first basalt interface).

Table 4-64. Statistical characteristics of uranium isotope background concentrations in lysimeter samples at the Subsurface Disposal Area.

Statistic	U-234		U-235			U-238		Total Uranium μg/L	U-234: U-238 Ratio	U-238: U-235 Ratio
	pCi/L	1σ	pCi/L	1σ	MDC	pCi/L	1σ			
Mean	2.26	0.57	0.29	0.24	0.85	1.07	0.38	3.3	2.15	1.89
Standard deviation	1.74	—	0.35	—	0.41	0.91	—	2.8	0.75	—
Minimum	-0.10	—	-0.30	—	0.08	-0.11	—	-0.4	—	—
Maximum	8.52	—	1.34	—	2.23	3.86	—	11.7	—	—
Mean + 3 standard deviations	7.49	—	1.34	—	—	3.81	—	11.6	—	—
Count	96	—	96	—	—	96	—	95	—	—

MDC = minimum detectable concentration

## 4.18.2 Waste Zone

Approximately 2.10 Ci of U-233, 63.5 Ci of U-234, 4.88 Ci of U-235, 1.43 Ci of U-236, and 141 Ci of U-238 were buried in the SDA (through 1999). An additional 0.0174 Ci of U-233, 0.407 Ci of U-234, 0.0382 Ci of U-235, 0.0175 Ci of U-236, and 7.39 Ci of U-238 are projected to be added by 2009, for totals of 2.12 Ci of U-233, 63.9 Ci of U-234, 4.92 Ci of U-235, 1.45 Ci of U-236, and 148 Ci of U-238. Most uranium is from weapons manufacturing waste, but INL Site operations also contributed a substantial portion. Waste streams containing U-233, -234, -235, -236, and -238 are identified in Table 4-4. Figures 4-19 through 4-23 illustrate densities of uranium isotopes in the buried waste.

**4.18.2.1 Waste Zone Gamma Spectral Logging.** The spectral gamma-logging tool provides no information about U-234. The gamma-logging tool detected U-235 based on the 186-keV gamma and U-238 based on the 1,001-keV gamma emitted by its progeny: Pa-234m. Table 4-65 presents detection rates above the noise level for probe holes, individual samples, and other detection data. Logging data are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6).

Table 4-65. Detection rates for uranium-235 and uranium-238 from the gamma-logging tool.

Isotope	Probehole Detection Rate (%)	Measurement Detection Rate (%)	Detection Limit (pCi/g) <sup>a</sup>	Maximum Concentration (pCi/g) <sup>a</sup>
U-235	44/135 (33)	261/4,863 (5)	2	345
U-238	70/135 (52)	862/4,863 (18)	25	220,894

a. Logging data are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6).

**4.18.2.2 Waste Zone Lysimeter Samples.** Between August 2001 and September 2005, 39 isotopic uranium analyses were performed on soil-moisture samples collected from 16 waste zone lysimeters in the SDA, yielding 25 U-233/U-234, 16 U-235/U-236, and 19 U-238 detections. To compare measured concentrations to the MCL, isotopic uranium results were converted from activity (pCi/L) to mass (µg/L) and summed; 16 of the summed results exceeded the total uranium MCL of 30 µg/L. Concentrations exceeding the MCL occurred in samples from the Americium/Neptunium Focus Area (741-08), Depleted Uranium Focus Area (DU-11), Enriched Uranium Focus Area (P5-UEU), Enriched Uranium Source Area (T3-EU), Irradiated Fuel Materials Area (T47-IF), and High Plutonium Density Area (P2-PU). Isotopic concentrations varied significantly, as expected in the waste zone, ranging from 2 pCi/L for U-235/236 to 109,000 pCi/L for U-233/234, where total uranium concentrations ranged from about 40 to 72,000 µg/L.

**4.18.2.3 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.** Three samples were analyzed (see Section 4.1.4.5) for radioactive constituents, including U-234, U-235, and U-238. Concentrations for U-234, U-235, and U-238 were 0.9 pCi/g, 0.04 pCi/g, and 0.9 pCi/g, respectively, and are consistent with natural background concentrations.

### 4.18.3 Surface

Between 1994 and 2004, 356 soil samples were collected in the RWMC area. Using gamma spectrometry, 95 samples were analyzed for U-234, U-235, and U-238. Thirty-five positive U-234 detections were identified ranging from  $0.45 \pm 0.13$  pCi/g at RW 2-2 outside RWMC in 2002 to  $1.3 \pm 0.2$  pCi/g north of the administrative area in 1997. Twenty-five positive detections of U-235 were identified, ranging from  $0.0046 \pm 0.0004$  pCi/g at location RW 3-4 in 2004 to  $0.196 \pm 0.021$  pCi/g at RW 6-3 in 2005. Thirty positive detections of U-238 were identified, ranging in concentration from  $0.11 \pm 0.20$  pCi/g at a location within the SDA to  $1.6 \pm 0.3$  pCi/g north of the administrative area in 1997. None of the samples exceeded the soil RBC used for comparison.

Between 1990 and 2004, 162 vegetation samples were collected from RWMC and control locations. Using gamma spectrometry, 49 samples were analyzed for U-234, U-235, and U-238. Twenty-one positive detections of U-234 were identified, ranging from  $(2.35 \pm 0.46) \text{E-}03$  pCi/g at RW 4 in 2004 to  $(3.04 \pm 0.51) \text{E-}02$  pCi/g at RW 2 in 2004. Eight positive detections of U-235 were identified, ranging from  $(1.01 \pm 0.37) \text{E-}03$  pCi/g at RW 4 in 2004 to  $(2.86 \pm 0.52) \text{E-}03$  pCi/g at Pad A in 2004. Nineteen positive detections of U-238 were identified, ranging in concentration from  $(1.98 \pm 0.44) \text{E-}03$  pCi/g at Frenchman's cabin to  $(3.0 \pm 0.2) \text{E-}02$  pCi/g at RW 2 in 2004.

Between 1991 and 2004, 237 surface run-off water samples were collected from RWMC and control locations. Using gamma spectrometry, about 103 samples were analyzed for U-234, U-235, and U-238. Thirty-one positive detections of U-234 were identified, ranging from  $0.0423 \pm 0.0128$  pCi/L at location TSA-3 in 1998 to  $0.335 \pm 0.069$  pCi/L at location TSA-1 in 1998. No positive detections of U-235

were identified. Thirty-one positive detections of U-238 were identified, ranging in concentration from  $0.0261 \pm 0.0086$  pCi/L at location TSA-3 in 1998 to  $0.37 \pm 0.08$  pCi/L at control location T-12 (i.e., outside the SDA) in 1998. All run-off concentrations were less than the MCL used for comparison.

#### **4.18.4 Vadose Zone**

The following subsections discuss distribution of uranium isotopes in vadose zone core, soil moisture, and perched water in various depth intervals.

##### **4.18.4.1 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.**

Three samples (see Section 4.1.4.5) were analyzed for U-233/234, U-235/236, and U-238, with no detections greater than surficial soil background upper 95% tolerance concentration limits.

**4.18.4.2 Lysimeter Samples at Depths of 0 to 35 ft.** Since 1997, 212 analyses for U-233/234, U-235/236, and U-238 have been performed on soil-moisture samples collected from 18 shallow lysimeters near RWMC. Concentrations exceeded upper background concentration levels in 66% (139) of the U-233/234 results, 32% (67) of the U-235/236 results, and 70% (149) of the U-238 results. To compare measured concentrations to the MCL, isotopic uranium results were converted from activity (pCi/L) to mass equivalents ( $\mu\text{g/L}$ ) and summed; almost 50% (103) of the shallow uranium results since 1997 exceeded the total uranium MCL of  $30 \mu\text{g/L}$ . Concentrations exceeding the MCL between 1997 and August 2005 were detected in nine lysimeters, six of which have a history of elevated concentrations (i.e., PA01:L15, PA02:L16, PA03:L33, W08:L13, W23:L07, and W23:L09) (see Tables 4-66, 4-67, and 4-68). Lysimeters with consistently elevated uranium concentrations are located in monitoring wells around Pad A (i.e., Wells PA01, PA02, and PA03), the western part of the SDA (i.e., Well W23), and near the Acid Pit (i.e., Well W08). In the Roback et al. (2000) study, using thermal ionization mass spectrometry, samples with elevated uranium concentrations (up to 144 ppb) were found to have natural U-238:U-235 isotope ratios and no U-236 was detected. Most of these samples were interpreted as natural uranium. Thus, natural background concentrations in these areas are higher than in other locations. Tables 4-79, 4-80, and 4-81 summarize concentration ranges, detection rates, and exceedances since 1997.

One previous observation in this depth range centered on changes and trends associated with U-238:U-235 activity ratios at some monitoring locations. Activity ratios for U-238:U-235, which are constant in nature, exhibited subtle changes at monitoring locations PA01:L15, PA02:L16, PA03:L33, and W23:L09. The isotopic ratios were used to erroneously conclude that enriched uranium, with a slight U-235 enrichment, was present at these locations. However, revised interpretation of U-238:U-235 and U-234:U-238 ratios (see Section 4.18.1) indicate the uranium is naturally occurring.

Table 4-66. Uranium-233/234 detections in shallow-depth (0 to 35 ft) lysimeters since 1997.

Uranium-233/234																				
Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																				
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																			
	2																			
	3							43												
	4							35												
1998	1																			
	2							55												
	3	8.7	4.8	6.4		36	25	46												
	4		4.4	8.9		39	29					4.5		27				60	49	3.8
1999	1	10	5.7	11		40	33	57				4.9							50	
	2	10																		
	3	12	4.3	14		36	29	53												
	4																			
2000	1	13						58				5.6								4.6
	2	10	4.5	14		36	26	62						29				71	64	
	3	13	5.2	20		42	28					6.7		30				76	66	4.8
	4	12	6.1	17		40	30													5.2
2001	1						24													
	2																			
	3	9.2	6.2	12		11	5.2				4.4	4.1						87		
	4																			



Table 4-66. (continued).

Uranium-233/234 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																				
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
2002	1																			
	2																			
	3		2.6			25						125				2.4				4.6
	4					37											68		38	5.7
2003	1		4.1	11	4.1									6.5			84			4.2
	2																			3.3
	3	8.4	2.9	12		34	33							19		2.0	73		63	4.8
	4	13				38	29							20			71		63	
2004	1			10		35	34							25		3.1	85			4.7
	2						33													3.8
	3			1.5			23										72		19	3.5
	4		4.3			44	20							19		4.9	59		55	4.0
2005	1		4.6			40	20									6.2				5.0
	2					39	21			5.5										
	3	11	4.2			41	17	48	3.8				3.1	11		4.4	54		45	4.4
	4		6.0	20		34	10	45	5.1					17			57		40	4.0
Note 1: The highest result is reported for duplicate samples or reanalysis.																				
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																				
For comparison, the maximum contaminant level = 30 µg/L for total uranium.																				
MCL = maximum contaminant level																				
	U-233/234 was analyzed, but not detected.																			
x.xx	U-233/234 was detected at or below local soil-moisture upper background concentration (8.52 pCi/L).																			
	U-233/234 was detected above local soil-moisture upper background, but less than the MCL.																			
	U-233/234 contributed to a detection greater than MCL for total uranium (see Note 2).																			

Table 4-67. Uranium-235/236 detections in shallow-depth (less than 35 ft) lysimeters since 1997.

Uranium-235/236															
Radioactive Waste Management Complex Lysimeters (0 to 35 ft)															
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14
1997	1														
	2														
	3							1.8							
	4							1.6							
1998	1														
	2							2.6							
	3							1.9							
	4					2.3	2.3							2.0	
1999	1		0.37	1.2		1.6	1.1	2.3				0.35			
	2														
	3					1.2									
	4														
2000	1							3.5							
	2			0.76		1.5	1.2	3.0						1.6	
	3	1.3		1.6		1.7	2.1					0.84		1.9	
	4					1.3									
2001	1														
	2														
	3														
	4													3.7	

Table 4-67. (continued).

Uranium-235/236 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																				
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
2002	1																			
	2																			
	3											3.7								
	4					3.3											10		6.1	
2003	1																2.9			
	2																			
	3					2.5	1.7							1.8			3.1		7.8	
	4					3.1	2.1							2.1			5.3		2.7	
2004	1					4.8	2.5							2.5			4.0			
	2						2.1													
	3						2.9										4.0			
	4																2.8		2.2	
2005	1																			
	2																			
	3					2.5	1.4	5.0									2.8		4.8	
	4					3.0		1.7									2.4			
Note 1: The highest result is reported for duplicate samples or reanalysis.																				
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																				
For comparison, the MCL = 30 µg/L for total uranium.																				
MCL = maximum contaminant level																				
	U-235/236 was analyzed for but not detected.																			
x.xx	U-235/236 was detected at or below local soil-moisture upper background concentration (1.34 pCi/L).																			
	U-235/236 was detected above soil-moisture upper background, but less than the MCL.																			
	U-235/236 contributed to a detection greater than the MCL for total uranium (see Note 2).																			

Table 4-68. Uranium-238 detections in shallow-depth (less than 35 ft) lysimeters since 1997.

Uranium-238 Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																				
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28
1997	1																			
	2																			
	3							34												
	4							26												
1998	1																			
	2							40												
	3	4.4	3.3	3.5		20	13	33												
	4		2.9	5.6		21	14					3.3		14				35	27	3.9
1999	1	7.0	3.2	6.3		24	16	41				3.6							29	
	2	6.1																		
	3	7.1	3.5	9.4		21	16	39												
	4																			
2000	1	9.7						42				3.7								3.5
	2	6.9	2.6	11		19	13	44						16				40	37	
	3	8.4	3.0	12		26	14					4.3		16				46	39	3.3
	4	8.8	2.8	9.1		24	15													3.7
2001	1						14													
	2																			
	3	7.7		7.2		7.1	3.6				3.9	3.9						53		
	4																			

Table 4-68. (continued).

Uranium-238																					
Radioactive Waste Management Complex Lysimeters (0 to 35 ft)																					
Fiscal Year	Quarter	98-1: L35	98-4: L38	98-5: L39	D15: DL07	PA01: L15	PA02: L16	PA03: L33	R1936: DL70	W05: L24	W05: L25	W06: L27	W08: L12	W08: L13	W08: L14	W09: L23	W23: L07	W23: L08	W23: L09	W25: L28	
2002	1																				
	2																				
	3		1.5			13						53				1.6				2.6	
	4					20											40		23	2.5	
2003	1		2.0	8.7										2.8				54			2.4
	2																			3.3	
	3	7.3	2.1			22	17							9.3		1.8	39		38	2.4	
	4	8.1				24	16							16			38		30		
2004	1			8.0		16	15							15			51				3.3
	2						16							12						2.2	
	3		3.1				11										41		9.4	2.2	
	4		2.1			21	11									2.7	37		32	3.4	
2005	1		2.7			23	9.5									3.6				2.8	
	2					26	11			3.1											
	3	5.2	2.1			23	8.7	39	4.3				1.6	11		3.3	33		30	2.8	
	4		2.4	12		22	5.5	32	4.3					8.7			38		28	3.2	
Note 1: The highest result is reported for duplicate samples or reanalysis.																					
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																					
For comparison, the MCL = 30 µg/L for total uranium.																					
MCL = maximum contaminant level																					
	U-238 was analyzed for but not detected.																				
x.xx	U-238 was detected at or below local soil-moisture upper background concentration (3.86 pCi/L).																				
	U-238 was detected above soil-moisture background, but less than the MCL.																				
	U-238 contributed to a detection greater than the MCL for total uranium (see Note 2).																				

Though isotopic ratios around Pad A, the western end of SDA, and the Acid Pit are within the range of naturally occurring uranium (Roback et al. 2000), other contaminants are detected in these locations. Presence of these other contaminants, in combination with higher uranium concentrations, could be interpreted as leachate influencing concentrations in these wells. This interpretation is supported by the following points:

- Uranium concentrations are significantly higher at these monitoring locations than all other lysimeters in this depth range
- Pad A contains a substantial portion (approximately 13%) of the total uranium buried in the SDA
- Aqueous waste solutions containing uranium from various INL Site processes were buried in the Acid Pit
- Other constituents often associated with uranium-bearing waste (e.g., from reactor operations) are detected at these locations
- Deep-depth lysimeters around Pad A (i.e., Lysimeters D06:DL01 and D06:DL02) exhibit similar uranium coincident with concentrations of other constituents.

Though concentrations at seven lysimeter locations are greater than the MCL for total uranium, concentrations remain relatively stable in five of the lysimeters, while decreasing in two (PA02:L16 and W08:L13) (see Figures 4-61 and 4-62).

To confirm that historical concentration and isotopic ratio trends at some lysimeter locations are being interpreted properly, additional soil-moisture samples were collected November 2004 from four lysimeters suspected of containing anthropogenic uranium (i.e., D06:DL01, D06:DL02, PA01:L15, and TW1:DL04) and analyzed by inductively coupled plasma-mass spectrometry (Koeppen et al. 2006). This analytical methodology can detect extremely low concentrations of uranium isotopes with very high precision. Table 4-69 provides the results along with monitoring results obtained by less-sensitive, routine alpha spectrometry measurements. Agreement was reasonable between U-234 and U-238 results; however, U-235 results did not compare well. In all cases, U-235 results obtained by alpha spectrometry were biased high, thus affecting calculated U-238:U-235 ratios. Therefore, conclusions formulated with historical alpha spectrometry measurements are questionable, and all uranium data were reevaluated. Sections 4.1.4.1 and 4.1.4.2 provide additional discussion.

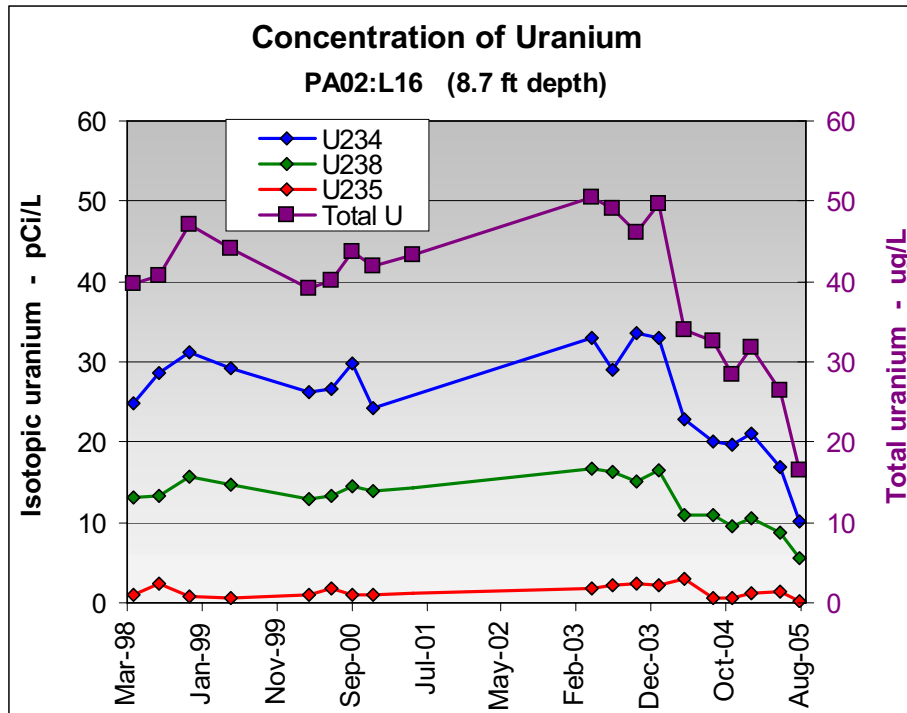


Figure 4-61. Uranium concentrations at Lysimeter PA02:L16 showing decreasing concentrations in early Fiscal Year 2004.

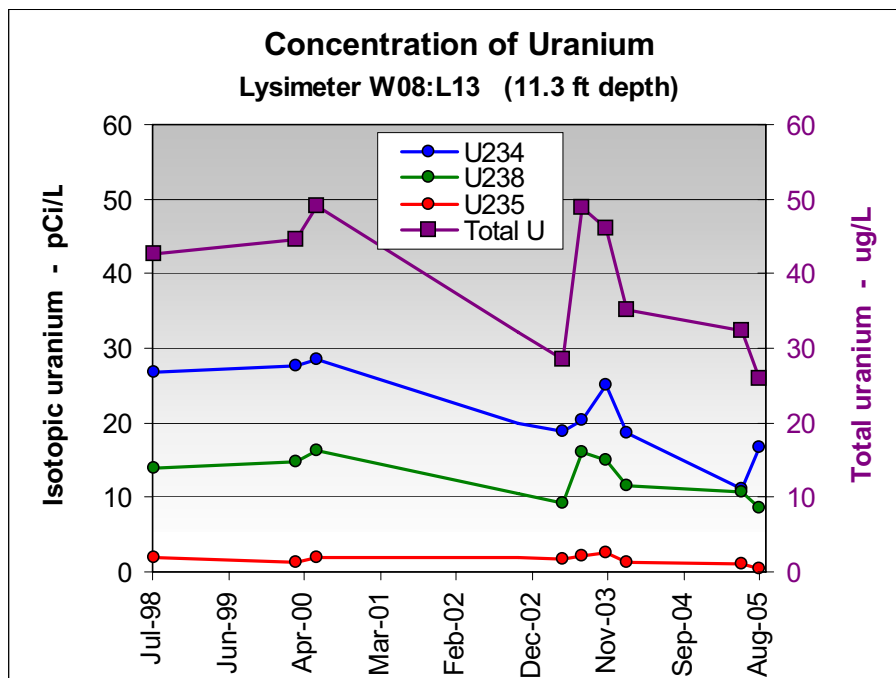


Figure 4-62. Uranium concentrations at Lysimeter W08:L13 showing decreasing concentrations beginning late in Fiscal Year 2003.

Table 4-69. Uranium concentrations measured by inductively coupled plasma-mass spectrometry and alpha spectrometry to assess isotopic ratios.

Lysimeter	Sample Date	Analytical Method	U-234 (pCi/L)	U-235 (pCi/L)	U-236 (pCi/L)	U-238 (pCi/L)	U-238: U-235 Ratio	U-234: U-238 Ratio
D06:DL01	11/15/04	ICP-MS <sup>a</sup>	74	1.9	<0.026	42	22.4	1.75
D06:DL02	11/15/04	ICP-MS <sup>a</sup>	95	1.7	<0.026	38	22.3	2.49
PA01:L15	11/15/04	ICP-MS <sup>a</sup>	39	0.88	<0.026	18	20.1	2.19
TW1:DL04	11/15/04	ICP-MS <sup>a</sup>	90	2.8	0.37	6.5	2.36	13.8
D06:DL01	11/15/04	ALS <sup>b</sup>	88 ± 7	2.8 ± 0.7	BDL	49 ± 4	18	1.8
D06:DL02	11/15/04	ALS <sup>b</sup>	100 ± 8	5.2 ± 1.0	BDL	39 ± 4	8	2.6
PA01:L15	11/15/04	ALS <sup>b</sup>	40 ± 4	0.9 ± 0.5	BDL	23 ± 3	26	1.7
TW1:DL04	11/15/04	ALS <sup>b</sup>	NS	NS	NS	NS	NA	NA
TW1:DL04	2/98 to 8/04 <sup>c</sup>	ALS <sup>b</sup>	91 ± 9	4.7 ± 0.9	BDL	9.1 ± 1.3	1.9	10.0
Natural uranium	—	—	—	—	—	—	21.7	~2.0 <sup>d</sup>

a. Inductively coupled plasma-mass spectrometry (special low-level analysis methodology).

b. Alpha spectrometry (routine analysis method).

c. Since a sample was not available for routine analysis in November 2004, the 6-year mean concentration was included for comparison with the inductively coupled plasma-mass spectrometry results.

d. Uranium-234 and U-238 in groundwater and soil moisture are not in secular equilibrium (i.e., the ratio is not 1:1).

ALS = alpha spectroscopy

BDL = below detection limit

NS = no sample

Ratios interpreted to be natural uranium (U- 238:U-235 ratios by alpha spectrometry reflect low accuracy of measurement)

Ratio indicative of anthropogenic uranium with slight U-235 enrichment

**4.18.4.3 Lysimeter Samples at Depths of 35 to 140 ft.** Since 1997, 176 analyses of U-233/234, U-235/236, and U-238 have been performed on soil-moisture samples collected from 14 shallow lysimeters near RWMC. About 37% (65) of U-233/234 and U-238, about 25% (44) of U-235/236, and 40% (71) of the U-238 soil-moisture concentrations in the 35 to 140-ft depth range exceeded upper background concentration levels. To compare measured concentrations to the MCL, isotopic uranium results were converted from activity (pCi/L) to mass equivalents (µg/L) and summed. Since 1997, almost 22% (39) of the intermediate-depth uranium results exceeded the total uranium MCL of 30 µg/L. Between 1997 and August 2005, analyses results exceeding the MCL involved five lysimeters, four of which have a history of elevated concentrations (i.e., D06:DL01, D06:DL02, I-1S:DL09, and TW1:DL04) (see Tables 4-70, 4-71, and 4-72). Lysimeters with consistently high uranium concentrations are located in monitoring wells near Pad A and Pit 5 (i.e., D06:DL01, D06:DL02, and TW1DL04) and the western part of the SDA (i.e., I-1S:DL09). Using thermal ionization mass spectrometry, the Roback et al. (2000) study found that samples with elevated uranium concentrations (up to 144 ppb) have natural U-238:U-235 isotope ratios, and no U-236 was detected. Most of these samples were interpreted as natural uranium. Thus, natural background concentrations in these areas are higher than in other locations. Concentrations greater than the MCL remain relatively constant at location I-1S:DL09, decreased slightly at locations D06:DL01 and D06:DL02, and increased at location TW1:DL04.

Figures 4-63, 4-64, and 4-65 illustrate concentration histories of those lysimeters where concentrations changed. Tables 4-79, 4-80, and 4-81 summarize concentration ranges, detection rates, and exceedances since 1997.



Table 4-70. Uranium-233/234 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Uranium-233/234																			
Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
1997	1																		
	2																		
	3		84																
	4	8.5	84																
1998	1																		
	2																		
	3		70	2.0															90
	4	48	82	2.4															83
1999	1	86		1.7															97
	2																		90
	3																		
	4																		
2000	1		96																94
	2																		91
	3	92		2.5	18			3.2	1.7	2.8			4.9						93
	4	111			16		10												87
2001	1												1.8						
	2																		
	3			3.8							7.3								5.2
	4																		
2002	1																		
	2																		
	3				17														
	4		96	6.0	15	2.4	2.0					3.1	4.2						

Table 4-70. (continued).

Uranium-233/234																			
Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
2003	1			2.1	21			4.4					2.9	3.0					57
	2				17	0.69	0.85					1.1	1.4	1.2					
	3	86	97	2.7	16	1.3	2.7	8.4		5.0		2.7	1.5	4.1					
	4	100		1.5	14		2.9	7.0		2.6		3.2	2.4	3.7					101
2004	1	87	99	2.0	14		3.3	6.8				2.4	1.8						96
	2				9.3			11		5.0		2.6	2.1						84*
	3	91	105		15	2.2	4.3	12		3.8									93
	4	84			17		4.0												121
2005	1	88	100		18			11		4.2				7.0					
	2				16	2.5	4.8	7.2											
	3	82	87	2.4			4.1	8.3		8.5				7.2	12		7.1		98
	4	84	48	1.9		1.5	5.1	6.8					2.4		11			3.1	
Note 1: The highest result is reported for duplicate samples or reanalysis.																			
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																			
For comparison, the MCL = 30 µg/L for total uranium.																			
* = result was initially associated with Lysimeter TW1:DL03; however, investigations in 2004 and 2005 revealed the sample was actually collected from Lysimeter TW1:DL04.																			
MCL = maximum contaminant level																			
		U-233/234 was analyzed, but not detected.																	
x.xx		U-233/234 was detected at or below local soil-moisture upper background concentration (8.52 pCi/L).																	
		U-233/234 was detected above local soil-moisture background, but less than the MCL.																	
		U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).																	

Table 4-71. Uranium-235/236 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Uranium-235/236																			
Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
1997	1																		
	2																		
	3		2.2																
	4		2.9																
1998	1																		
	2																		4.1
	3		2.4																2.9
	4	1.7	2.5																4.7
1999	1	2.8																	4.3
	2																		4.3
	3																		
	4																		
2000	1		3.2																5.7
	2																		4.1
	3	3.3		1.0	1.4			0.78	0.90				0.65						8.2
	4	2.9																	4.3
2001	1																		
	2																		
	3																		
	4																		
2002	1																		
	2																		
	3																		
	4		3.7		2.6			1.2											

Table 4-71. (continued).

Uranium-235/236 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
2003	1							1.7											1.8
	2																		
	3	10	17					0.71						0.95					
	4	6.0																	4.8
2004	1		9.4																6.3
	2																		4.5*
	3	4.5	2.9																8.8
	4	2.8																	5.1
2005	1	2.8	5.2																
	2																		
	3	4.9	4.4														2.8		9.5
	4		2.2																
Note 1: The highest result is reported for duplicate samples or reanalysis.																			
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																			
For comparison, the MCL = 30 µg/L for total uranium.																			
* = result was initially associated with Lysimeter TW1:DL03; however, investigations in 2004 and 2005 revealed the sample was actually collected from Lysimeter TW1:DL04.																			
MCL = maximum contaminant level																			
x.xx		U-235/236 was analyzed, but not detected.																	
		U-235/236 was detected at or below local soil-moisture upper background concentration (1.34 pCi/L).																	
		U-235/236 was detected above local soil-moisture background, but less than the MCL.																	
		U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).																	

Table 4-72. Uranium-238 detections in intermediate-depth (35 to 140 ft) lysimeters since 1997.

Uranium-238 Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
1997	1																		
	2																		
	3		49																
	4	7.2	42																
1998	1																		
	2																		
	3		42																9.8
	4	28	49	1.2															8.2
1999	1	49		0.68															9.5
	2																		9.6
	3																		9.1
	4																		
2000	1		47																9.6
	2																		9.6
	3	41		1.6	10		1.5	2.1	1.3	3.1									9.1
	4	53			9.3		4.5												8.9
2001	1												0.87						
	2																		
	3										4.7								2.6
	4																		
2002	1																		
	2																		
	3				9.4			1.7											
	4		42		8.9			3.6											

Table 4-72. (continued).

Uranium-238																			
Radioactive Waste Management Complex Lysimeters (35 to 140 ft)																			
Fiscal Year	Quarter	D06: DL01	D06: DL02	D15: DL06	I-1S: DL09	I-2S: DL11	I-3S: DL13	I-4S: DL15	I-5S: DL16	O2: DL20	O3: DL22	O4: DL24	O5: DL25	O7: DL28	R1935: DL60	1936: DL68	R2004: DL50	R2006: DL46	TW1: DL04
2003	1				9.9	1.4		2.4					1.4	1.3					5.1
	2				8.4	0.60						0.39	0.56	0.44					
	3	44	39		9.9	0.89		4.7				1.0	1.7	1.1					
	4	45			8.3		2.1	4.2						2.5					9.3
2004	1	42	48		8.8		2.2	4.3						1.6					7.8
	2				4.8			4.1		1.7									8.7*
	3	48	45		12		3.1	6.0		3.2									10
	4	47			8.4		3.3												15
2005	1	49	39		12		2.9			3.4									
	2				10		1.8	4.3											
	3	43	40				2.1	5.2		2.6				3.0	11		2.6		12
	4	29	41					4.5							11			3.6	
Note 1: The highest result is reported for duplicate samples or reanalysis.																			
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																			
For comparison, the MCL = 30 µg/L for total uranium.																			
* = result was initially associated with Lysimeter TW1:DL03; however, investigations in 2004 and 2005 revealed the sample was actually collected from Lysimeter TW1:DL04.																			
MCL = maximum contaminant level																			
		U-238 was analyzed, but not detected.																	
x.xx		U-238 was detected at or below local soil-moisture upper background concentration (3.86pCi/L).																	
		U-238 was detected above local soil-moisture background, but less than the MCL.																	
		U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).																	

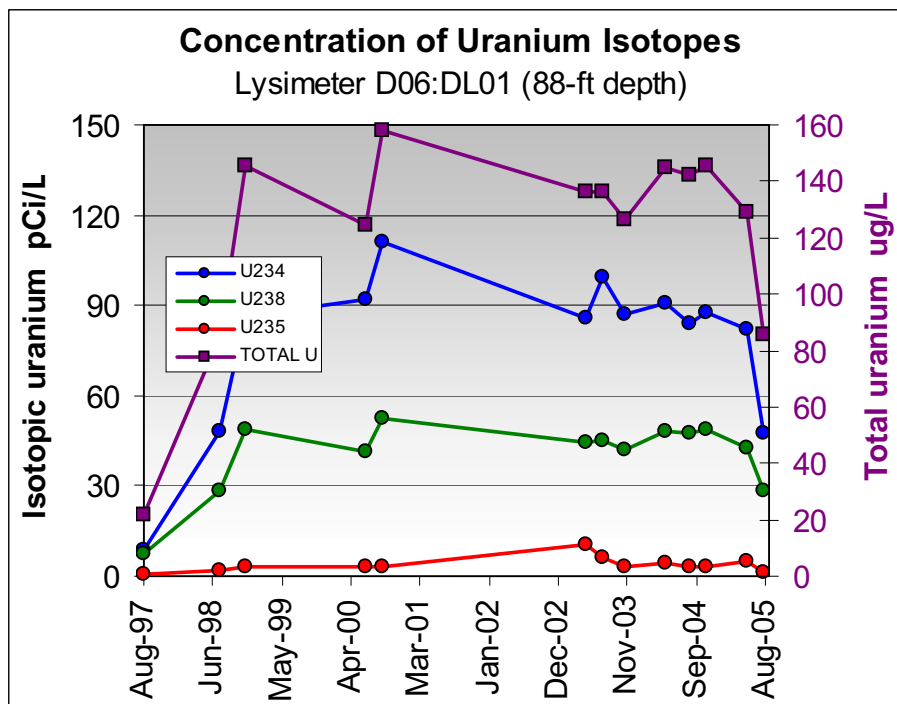


Figure 4-63. Uranium concentrations at Lysimeter D06:DL01.

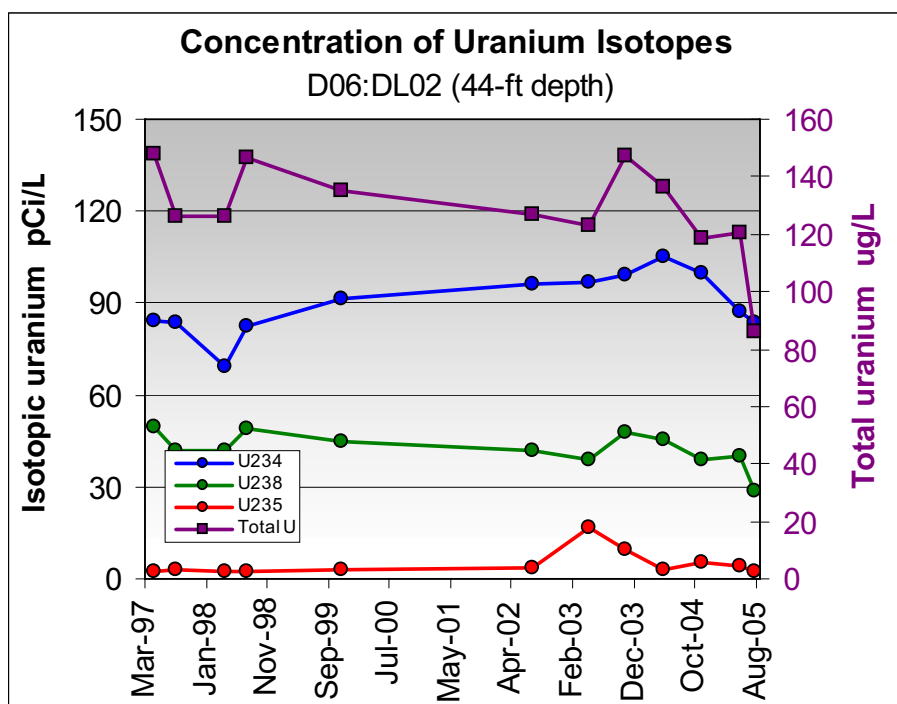


Figure 4-64. Decreasing uranium concentrations at Lysimeter D06:DL02.

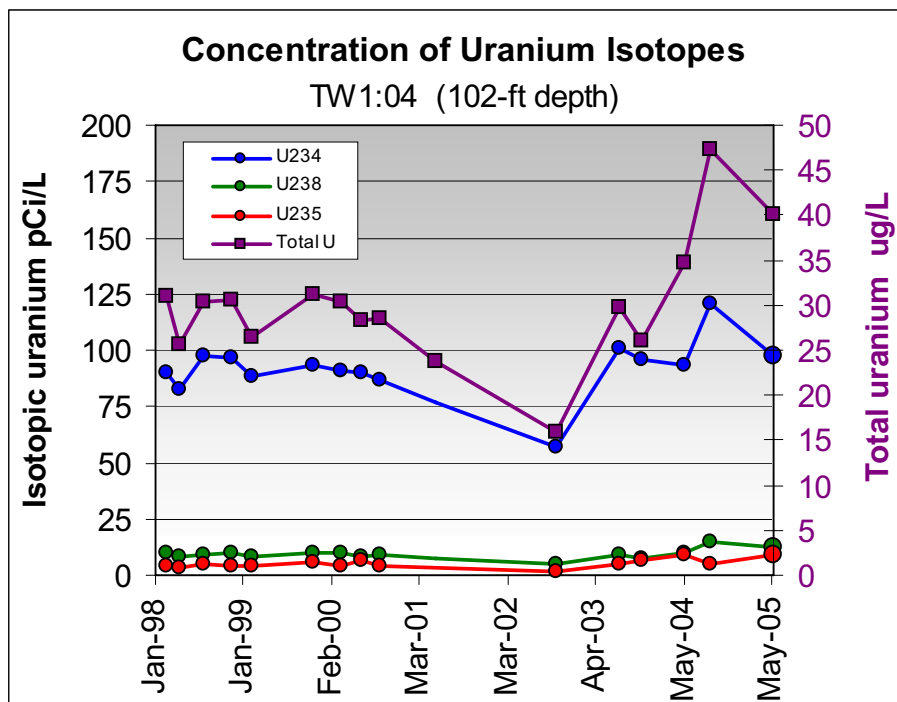


Figure 4-65. Increasing uranium concentrations at Lysimeter TW1:DL04.

One previous observation in this depth range involves U-238:U-235 activity ratios at some monitoring locations. Activity ratios for U-238:U-235, which are constant in nature, were interpreted to exhibit changes at monitoring locations D06:DL01 and D06:DL02. The U-238:U-235 activity ratios at the other two elevated lysimeter locations (i.e., I-1S:DL09 and TW1:DL04) also were thought to indicate the presence of slightly enriched uranium. Isotopic ratios were used to conclude (erroneously) that enriched uranium with a slight U-235 enrichment was present at these locations. However, revised interpretations of U-238:U-235 ratios (see Section 4.18.1) find no conclusive evidence that enriched uranium is present. Uranium concentrations at locations D06:DL01, D06:DL02, and I-1S:DL09 are interpreted as naturally occurring, while TW1:DL04 shows anthropogenic uranium with slight U-235 enrichment (see Figure 4-69 in Section 4.18.5). The interpretation that uranium concentrations up to 144 ppb may be naturally occurring is supported by Roback et al. (2000), which shows that such concentrations may have natural uranium isotopic ratios and have no U-236.

Isotopic ratios at TW1:DL04 clearly indicate uranium at this location is anthropogenic and slightly enriched with U-235. This interpretation is further supported by thermal ionization mass spectrometry analysis of a TW1 sample in 1999 (Roback et al. 2000). As shown in Figure 4-65, the total uranium concentration (and, though less obvious, the U-235 concentration) has gradually increased since the latter part of 2002.



Though isotopic ratios around Pad A (i.e., locations D06:DL01 and D06:DL02) and the western end of SDA (I-1S:DL09) are within the range of naturally occurring uranium, other contaminants are detected in these locations. Presence of these other contaminants in combination with higher uranium concentrations could be interpreted as leachate influencing concentrations in these wells. This interpretation is supported by the following points:

- Uranium concentrations are significantly higher at these monitoring locations than all other lysimeters in this depth range
- Pad A contains a substantial portion (approximately 13%) of the total uranium buried in the SDA
- Other constituents often associated with uranium-bearing waste (e.g., from reactor operations) are detected at these locations
- Shallow-depth lysimeters around Pad A (i.e., Lysimeters PA01:L15, PA02:L16, and PA03:L33) exhibit similar uranium coincident with concentrations of other constituents.

Soil-moisture samples were collected November 2004 at locations suspected of containing anthropogenic uranium (i.e., Wells D06 and TW1) and analyzed by inductively coupled plasma-mass spectrometry (see discussion in the previous section). This analytical methodology detects extremely low concentrations with very high precision and confirmed the presence of anthropogenic uranium and its U-235 enrichment. This test was performed to confirm that historical concentrations and isotopic ratios at these locations are being interpreted correctly. Table 4-69 provides results obtained with both analytical methods. Agreement was reasonable between U-234 and U-238 results; however, U-235 results did not compare well. In all cases, U-235 results obtained by alpha spectrometry were biased high, thus affecting calculated U-238:U-235 ratios. Therefore, conclusions formulated with historical alpha spectrometry measurements are erroneous, and all uranium data are reevaluated. Sections 4.1.4.1 and 4.1.4.2 provide additional discussion.

**4.18.4.4 Lysimeter and Perched Water Samples at Depths Greater Than 140 ft.** Since 1997, 170 analyses of U-233/234, U-235/236, and U-238 were performed on soil-moisture samples collected from 29 lysimeters and five perched water wells near RWMC. About 5% (eight) of the U-233/234, 1% (two) of the U-235/236, and 8% (14) of the U-238 soil-moisture concentrations in this depth range exceeded upper background concentration levels. In comparing measured concentrations to the MCL, isotopic uranium results were converted from activity (pCi/L) to mass equivalents ( $\mu\text{g/L}$ ) and summed; 2.3% (four) of the uranium results since 1997 exceeded the total uranium MCL of 30  $\mu\text{g/L}$ . Between 1997 and August 2005, analyses results exceeded the MCL in Lysimeters IE6:DL34, R1936:DL63, R1936:DL65, none of which have a history of elevated concentrations. Before these recent exceedances, no uranium concentrations in this depth interval exceeded the total uranium MCL. Tables 4-73, 4-74, and 4-75 show U-233/234, U-235/236, and U-238 detections in deep (deeper than 140 ft) lysimeters and perched water since 1997.

Three samples have been collected from Lysimeter R1936:DL63 and one from Lysimeter R1936:DL65 since monitoring Well R1936 was installed in 2004. Thus, insufficient data are available to properly evaluate uranium results and to assess trends at these locations. A significant increase and concentration trend developed recently at location IE6:DL34 (see Figure 4-66). Subtle changes in uranium concentrations began between August 2004 and February 2005, with the most notable changes occurring after February 2005. Besides uranium, VOCs and tritium also were detected above background at this location. Tables 4-79, 4-80, and 4-81 list isotopic uranium results exceeding local soil-moisture upper background concentrations, including the calculated total uranium concentration and MCL exceedances.

Preceding figures show uranium concentrations at most deep monitoring locations are near background values. Uranium concentration trends or isotopic ratio trends associated with any of the deep vadose zone monitoring wells are not discernable. All detections in soil moisture at this depth and location are consistent with natural uranium.

**4.18.4.5 Vadose Zone Core Samples.** Between 1993 and 2003, a total of 100 vadose zone core samples were analyzed for U-233/234, 99 were analyzed for U-235/236, and 109 were analyzed for U-238. Most results were below the INL Site surface soil background concentration limits (Rood, Harris, and White 1996) and soil RBCs used for comparison.

The most recent core sampling (2003) focused on the B-C and C-D sedimentary interbeds beneath RWMC. Uranium was not detected above background tolerance limits in any of the 13 interbed samples that were evaluated. These nondetections are not comparable to previous core sample detections because samples were not collected at the same interbed locations. The only core locations near one another are DE4 (2004) and I4D (2000) in the southwestern corner of Pad A. Uranium-233/234, U-235/236, and U-238 results from locations DE4 and I4D, at comparable depths, correlate well as measured concentrations and are typical of natural uranium in both locations.

Most U-238 results above soil background concentrations were associated with samples of fractured basalt and samples from the rubble zone, not soil. Comparing results should be viewed in that context. The U-238 results were qualified as questionable (J-flagged) because the laboratory method blank contained detectable (0.2 pCi/g) U-238. Positive U-238 results are presented here even though the laboratory method blank contained detectable U-238 because the concentration of the blank was minimal (0.2 pCi/g) compared to sample results.

The U-238:U-235 and U-234:U-238 activity ratios were evaluated to assess anthropogenic influences at these depths and sample locations. Activity ratios of U-234:U-238 varied from 0.13 to 3.21, and U-238:U-235 ratios varied from 4.9 to 39.5. Such wide variations are likely caused by inaccuracy of the measurement, which increases in low-concentration samples. Varying amounts of uranium activity in the different types of sample material (e.g., fractured basalt, massive basalt, rubble, sediment, and sand) also influences results. Therefore, an anthropogenic influence could not be adequately determined. Unfortunately, early core samples (1971 to 1987) were not analyzed for isotopic uranium.





Table 4-75. Uranium-238 detections in deep (greater than 140 ft) lysimeters and perched water since 1997.

Uranium-238																																					
Radioactive Waste Management Complex Perched Water and Lysimeters (>140 ft)																																					
Fiscal Year	Quarter	8802D	DE4: DL33	DE7: DL36	DE7: DL37	D10	I2D: DL10	I3D: DL12	I4D: DL14	IE3: DL30	IE4: DL32	IE6: DL34	IE7: DL35	IE8: DL38	O2: DL19	O3: DL21	O4: DL23	O6: DL26	O7: DL27	O8: DL29	DL52	DL54	DL55	DL56	DL57	DL58	DL62	DL63	DL65	R1936: DL67	R1936: DL63	R1936: DL65	R1936: DL67	R2006: DL43	S1898: DL40	USGS-092	
1997	1																																				
	2																																				
	3																																				
	4																																				
1998	1																																				
	2																																				
	3																																				
	4																																				
1999	1																																				3.6
	2																																			4.7	
	3																																				
	4																																				
2000	1																																			1.3	
	2																																		3.2		
	3																																				
	4																																				
2001	1																																				
	2																																				
	3																																				
	4																																				
2002	1																																			3.2	
	2																																				
	3																																				
	4																																				
2003	1							1.0						3.0																					3.7		
	2												1.6																					2.1			
	3																																	1.4			
	4																																	2.6			
2004	1									7.8	2.4									2.5																	
	2									7.4																											
	3									3.2			2.8																								
	4	3.3	2.4				1.9			2.0			4.3						2.8																		
2005	1									2.6																											
	2									2.1																											
	3	2.2	1.2				2.4					3.6							3.0							6.7					12	2.7		2.0	1.9		
	4									2.2			22													7.0						11			2.5		
Note 1: The highest result is reported for duplicate samples or reanalysis.																																					
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																																					
For comparison, the MCL = 30 µg/L for total uranium.																																					
MCL = maximum contaminant level																																					
U-238 was analyzed, but not detected.																																					
x.xx	U-238 was detected at or below local soil-moisture upper background concentration (3.86 µCi/L).																																				
	U-238 was detected above local soil-moisture background, but less than the MCL.																																				
	U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).																																				

Note 1: The highest result is reported for duplicate samples or reanalysis.

Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).

For comparison, the MCL = 30 µg/L for total uranium.

MCL = maximum contaminant level

U-238 was analyzed, but not detected.

x.xx U-238 was detected at or below local soil-moisture upper background concentration (3.86 µCi/L).

U-238 was detected above local soil-moisture background, but less than the MCL.

U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).



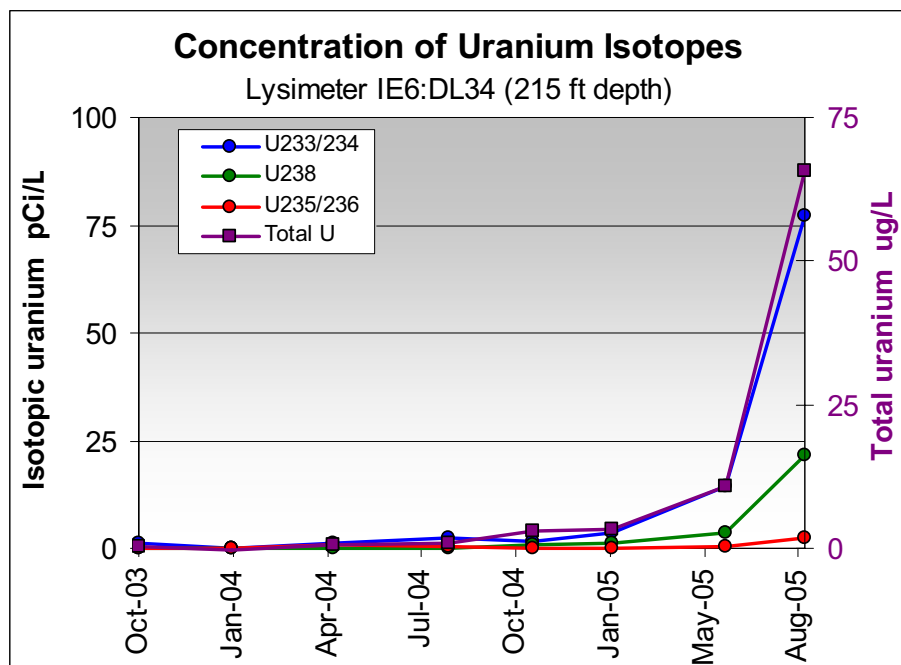


Figure 4-66. Uranium concentration trend at location IE6:DL34.

#### 4.18.5 Aquifer

Since 1998, 386 analyses of U-233/234, and 385 analyses of U-235/236 and U-238 were performed on aquifer samples collected from 16 monitoring wells near RWMC. About 1% (four) of the U-233/234, 2.6% (10) of the U-235, and 0.5% (two) of the U-238 detections exceeded upper background concentration limits (see Tables 4-76, 4-77, and 4-78). However, the total uranium concentration has never exceeded the MCL of 30  $\mu\text{g/L}$ . Tables 4-79, 4-80, and 4-81 present a summary of concentration ranges, detection rates, and exceedances since 1998.

The USGS does not analyze for uranium in the eight wells that they manage, control, and routinely sample.

Historical observations about uranium in the aquifer involve (1) increasing concentrations of U-235/236 at Wells M12S and M13S and (2) changes and trends in U-238:U-235 activity ratios (see Figure 4-67). These changes and trends were initially attributed to anthropogenic uranium from upgradient sources (Koeppen et al. 2005) because low concentrations of anthropogenic uranium were detected in aquifer monitoring wells downgradient of INTEC (Roback et al. 2001). Additional U-235/236 data have been acquired since FY 2004, and as shown in Figure 4-67, U-235/236 concentrations have decreased and are more typical of aquifer background concentrations. The apparent trend may have been an artifact of the relatively high uncertainties associated with U-235/236 measurements. Based on current interpretations of U-238:U-235 and U-234:U-238 ratios (see Section 4.18.1), concentrations at Well M12S are characteristic of naturally occurring uranium (see Figure 4-68). Correlation between activity ratios in Figure 4-68 shows that U-234:U-238 uranium ratios at Well M12S are characteristic of naturally occurring uranium. However, decreased U-238:U-235 ratios should show increased U-234:U-238, even for low-enriched uranium (graphed as artificial data point). Highly enriched uranium would show an even greater increase in the U-234:U-238 ratio for a small decrease in the U-238:U-235 ratio.

Table 4-76. Uranium-233/234 detections in aquifer wells since 1998.

Uranium-233/234 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Fiscal Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11 A31	OW-2	USGS-127
1998	1																
	2																
	3	0.78	1.4	0.49	1.1	1.4	0.73										
	4	1.0	1.7	0.61	1.3	1.5	0.93	1.3	1.4	1.4	1.4						
1999	1	0.91	1.5	0.53	1.2	1.4	0.72	1.3	1.3	1.5	1.5						
	2	0.90	1.4	0.44	1.2	1.3	0.79	1.2	1.4	1.2	1.4						
	3	0.93	1.4	0.42	1.2	1.3	0.66	1.4	1.5	1.4	1.5						
	4	0.87	1.4	0.42	1.2	1.1	0.71	1.3		1.5	1.2						
2000	1	0.87	1.3	1.5	1.2	1.3	0.79	1.2	1.4	1.2	1.4						
	2	0.89		0.40	1.2	1.3	0.57	1.3	1.3	1.3	1.5	1.1	1.4				
	3													1.2			
	4	0.89	1.4	0.42	1.3	1.4	0.63	1.2	1.4	1.3	1.6	1.2	1.3	1.3			0.99
2001	1	1.1	1.3	0.52	1.1	1.3	0.84	1.2		1.2	1.7	0.84	1.3	1.2	0.90	1.8	1.0
	2	0.89	1.6		1.1	1.2		1.1	1.6	1.1	1.3	1.1	1.2	1.2	0.92	1.6	1.1
	3	0.85	1.4	0.56	1.1	1.3		1.1	1.4	1.3	1.3	1.2	1.2	1.2	1.2	1.5	1.0
	4	0.78	1.5	0.55	1.1	1.3		1.2	1.4	3.7	4.3	1.1	1.3	1.1		1.6	1.0
2002	1	0.89	1.4	0.45	1.3	1.3		1.2	1.5	1.3	1.4	1.2	1.3	1.3	0.95	1.5	1.0
	2	0.91	1.5	0.47	1.2	1.3		1.3	1.3	1.2	1.4	1.2	1.2	1.2	0.94	1.6	0.99
	3	0.82	1.4	1.7	1.1	1.4			1.4	1.4	1.6	1.1	1.4	1.3	1.4	0.51	1.0
	4	0.86	1.3	0.45	1.3	1.2		1.3	1.4	1.4	1.5	1.1	1.6	1.3	1.2	1.5	1.1
2003	1	0.83	1.3	0.46	1.2	1.4		1.3	1.5	1.4	1.5	1.2	1.3	1.2	1.2	1.7	1.0
	2	0.86	1.4	0.41	1.2	1.4			1.5	1.4	1.6	1.1	1.3	1.2	1.7	1.8	1.1
	3	0.92	1.4	0.43	1.1	1.3			1.3	1.3	1.3	1.1	1.3	1.1	1.2	1.6	1.1
	4	0.90	1.5	0.40	1.3	1.4		1.2	1.6	1.4	1.5	1.3	1.4	1.2	1.6	2.0	1.1
2004	1	0.77	1.5	0.40	1.2	1.3		1.3	1.4	1.3	1.5	1.1	1.3	1.1	1.5	1.6	1.1
	2	0.86	1.5	0.38	1.1	1.4		1.3	1.5	1.2	1.5	1.1	1.3	1.3	1.6	1.8	1.1
	3	0.92	1.5	0.48	1.2	1.3		1.2	1.5	1.4	1.3	1.2	1.3		1.1	2.1	1.2
2005	1	0.81	1.4	0.42	1.3	1.3		1.2	1.5	1.3	1.3	1.3	1.4	1.1	1.4	1.7	0.97
	2	0.94	1.4	0.51	1.5	1.3		1.4	1.7	1.2	1.3	1.1	1.3	1.2	1.4	1.8	1.1

Note 1: The highest result is reported for duplicate samples or reanalysis.

Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).

For comparison, the MCL = 30 µg/L for total uranium.

MCL = maximum contaminant level

U-233/234 was analyzed, but not detected.

x.xx U-233/234 was detected at or below aquifer background upper tolerance limits (1.92 pCi/L).

U-233/234 was detected above aquifer background tolerance limits but less than the MCL.

U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).

Well is out of service. Well was rendered inoperable after repairs were unsuccessful.



Table 4-77. Uranium-235/236 detections in aquifer wells since 1998.

Uranium-235/236 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11 A31	OW-2	USGS- 127
1998	1																
	2																
	3																
	4	0.09		0.04	0.09	0.09		0.08	0.08	0.05							
1999	1																
	2		0.06						0.04	0.04	0.07						
	3	0.05				0.04		0.04	0.04		0.05						
	4		0.04					0.04									
2000	1		0.04		0.03	0.05			0.03		0.03						
	2				0.05			0.06	0.06	0.06	0.05						
	3													0.04			
	4		0.04		0.04				0.03		0.04		0.04				
2001	1	0.04	0.05			0.05	0.03	0.03		0.04	0.06	0.02		0.04	0.05		0.03
	2																
	3		0.04		0.05	0.05		0.03	0.06	0.04	0.05	0.06	0.11	0.04		0.18	
	4	0.04	0.30		0.20			0.08	0.08	0.27		0.06					
2002	1		0.14		0.05	0.04		0.06						0.08		0.08	0.06
	2		0.03		0.06	0.05		0.05	0.05	0.05	0.06	0.08		0.07		0.06	0.04
	3			0.05	0.07							0.05	0.05		0.07		
	4		0.07		0.05				0.08		0.07		0.06	0.07	0.04	0.18	
2003	1		0.07						0.11	0.04		0.04				0.05	0.05
	2		0.05	0.03	0.04	0.05			0.03	0.04		0.04	0.05		0.05	0.14	
	3	0.04	0.11	0.04	0.07	0.09			0.11	0.07	0.06	0.06	0.15	0.10	0.08	0.06	0.05
	4		0.06		0.07				0.12		0.07	0.26	0.09	0.11	0.08	0.06	
2004	1		0.06		0.06			0.10	0.13	0.10	0.08	0.11	0.06	0.08	0.06	0.22	0.09
	2		0.06			0.16		0.09	0.12	0.08	0.09		0.04			0.07	
	3	0.10	0.13		0.06			0.04	0.22	0.14	0.22	0.08	0.14		0.13	0.10	0.08
2005	1			0.03	0.03	0.04					0.06		0.06	0.05	0.02	0.05	
	2		0.08			0.08		0.05	0.09	0.09	0.11	0.06	0.07	0.12			

Note 1: The highest result is reported for duplicate samples or reanalysis.

Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).

For comparison, the MCL = 30 µg/L for total uranium.

MCL = maximum contaminant level

	U-235/236 was analyzed, but not detected.
x.xx	U-235/236 was detected at or below aquifer upper background (0.15 pCi/L).
	U-235/236 was detected above aquifer background, but less than the MCL.
	U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.

Table 4-78. Uranium-238 detections in aquifer wells since 1998.

Uranium-238 Radioactive Waste Management Complex Aquifer Monitoring Wells																	
Year	Qtr	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11 A31	OW-2	USGS- 127
1998	1																
	2																
	3	0.35	0.60	0.25	0.54	0.56	0.42										
	4	0.53	0.64	0.33	0.65	0.74	0.46	0.66	0.72	0.69	0.58						
1999	1	0.35	0.66	0.29	0.57	0.58	0.38	0.62	0.49	0.51	0.73						
	2	0.38	0.73	0.23	0.60	0.51	0.35	0.53	0.75	0.54	0.63						
	3	0.43	0.62	0.32	0.58	0.67	0.27	0.55	0.72	0.54	0.71						
	4	0.34	0.65	0.28	0.53	0.52	0.32	0.52		0.55	0.65						
2000	1	0.40	0.65	0.67	0.58	0.69	0.35	0.50	0.64	0.48	0.60						
	2	0.46	0.68	0.22	0.56	0.58	0.28	0.57	0.61	0.55	0.62	0.57	0.66				
	3													0.63			
	4	0.43	0.72	0.23	0.52	0.68	0.33	0.47	0.68	0.61	0.67	0.55	0.60	0.58			0.49
2001	1	0.53	0.60	0.25	0.45	0.65	0.37	0.44		0.51	0.71	0.39	0.59	0.60	0.41	0.88	0.57
	2	0.41	0.77	0.25	0.45	0.45		0.49	0.58	0.54	0.58	0.51	0.63	0.63	0.48	0.85	0.64
	3	0.41	0.65	0.30	0.58	0.62		0.42	0.67	0.49	0.60	0.56	0.53	0.51	0.54	0.64	0.50
	4	0.38	0.46	0.32	0.57	0.60		0.44	0.64	1.71	2.12	0.50	0.64	0.48		0.89	0.47
2002	1	0.42	0.59	0.28	0.62	0.56		0.47	0.60	0.54	0.65	0.54	0.62	0.70	0.41	0.75	0.44
	2	0.36	0.59	0.28	0.54	0.59		0.54	0.60	0.54	0.60	0.51	0.67	0.51	0.44	0.75	0.50
	3	0.40	0.57	0.78	0.44	0.67			0.54	0.54	0.54	0.58	0.65	0.60	0.64	0.18	0.59
	4	0.42	0.57	0.23	0.54	0.54		0.61	0.62	0.63	0.71	0.49	0.89	0.63	0.53	0.73	0.58
2003	1	0.43	0.58	0.20	0.62	0.52		0.47	0.67	0.60	0.65	0.58	0.59	0.59	0.60	0.86	0.50
	2	0.42	0.66	0.27	0.54	0.65			0.73	0.58	0.68	0.57	0.65	0.51	0.81	0.89	0.52
	3	0.39	0.62	0.22	0.56	0.56			0.57	0.52	0.66	0.55	0.56	0.51	0.53	0.76	0.51
	4	0.38	0.64	0.28	0.61	0.64		0.43	0.61	0.62	0.67	0.66	0.58	0.53	0.90	0.85	0.51
2004	1	0.34	0.63	0.20	0.60	0.66		0.53	0.64	0.56	0.63	0.54	0.58	0.54	0.65	0.85	0.49
	2	0.38	0.63	0.20	0.46	0.68		0.50	0.71	0.68	0.59	0.59	0.65	0.54	0.78	0.90	0.49
	3	0.35	0.53	0.17	0.56	0.59		0.55	0.58	0.60	0.57	0.49	0.63		0.57	0.84	0.44
2005	1	0.38	0.57	0.20	0.65	0.70		0.44	0.73	0.61	0.82	0.66	0.60	0.61	0.62	0.88	0.54
	2	0.46	0.54	0.24	0.70	0.69		0.56	0.65	0.66	0.71	0.55	0.71	0.56	0.60	0.89	0.52
Note 1: The highest result is reported for duplicate samples or reanalysis.																	
Note 2: For comparison to the total uranium MCL, measured U-233/234 activities are converted to mass equivalents and combined with measured U-235/236 and U-238 mass equivalents. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL (pink square).																	
For comparison, the MCL = 30 µg/L for total uranium.																	
MCL = maximum contaminant level																	
	U-238 was analyzed, but not detected.																
x.xx	U-238 was detected at or below aquifer upper background tolerance limits (0.9 pCi/L).																
	U-238 was detected above aquifer background, but less than the MCL .																
	U-233/234 contributed to a detection greater than the MCL for total uranium (see Note 2).																
	Well is out of service. Well was rendered inoperable after repairs were unsuccessful.																

Table 4-79. Concentration ranges and detection frequencies of uranium-233/234 results greater than background levels for sampled media since 1998.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations Above Background <sup>c</sup>		
					Minimum	Mean	Maximum
Surface soil	0.0	0/356	0	NA	NA	NA	NA
Surface vegetation	0.0	0/162	0	NA	NA	NA	NA
Surface run-off	0.0	0/237	0	NA	NA	NA	NA
Vadose zone (0 to 35 ft)							
Cores	0.0	0/9	0	None	NA	NA	NA
Soil moisture	65.6	139/212	103 <sup>d</sup>	98-5, PA01, PA02, PA03, W06, W08, W23	9 ± 2	35 ± 3	125 ± 10
Vadose zone (35 to 140 ft)							
Cores	2.4	1/41	0	None	NA	NA	1.7 ± 0.10
Soil moisture	36.9	65/176	39 <sup>d</sup>	D06, IIS, R1935, TW1	8.6 ± 1.2	64 ± 6	121 ± 10
Vadose zone (140 to 250 ft)							
Cores	0.0	1/49	0	None	NA	NA	NA
Soil moisture and perched water	3.8	5/133	2 <sup>d</sup>	IE6, R1936	10.1 ± 1.6	25 ± 3	77 ± 6
Vadose zone (>250 ft)							
Cores	0.0	0/0	NA	NA	NA	NA	NA
Soil moisture	8.1	3/37	2 <sup>d</sup>	R1936	8.8 ± 1.6	11.1 ± 1.6	12.4 ± 1.6
Aquifer	1.0	4/386	0	None	2.01 ± 0.18	3.0 ± 0.3	4.3 ± 0.4

a. Ratio = number of detections greater than upper background levels/number of sample analyses.

b. Comparison concentrations (i.e., risk-based concentrations and MCLs) are provided in Table 4-1.

c. The following U-234 upper background concentration levels were applied to the various sample media (see Table 4-1):

- 1.44 pCi/g was applied to surface soil, vegetation, and core samples
- 1.92 pCi/L was applied to run-off water and aquifer samples
- 8.52 pCi/L was applied to soil-moisture samples.

d. The value shown is the number of times the isotope contributed to a detection that exceeded the MCL of 30 µg/L for total uranium. Measured U-233/234, U-235/236, and U-238 activities are converted to mass equivalents and combined. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL.

MCL = maximum contaminant level

Table 4-80. Concentration ranges and detection frequencies of uranium-235/236 results greater than background levels for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations Above Background <sup>c</sup>		
					Minimum	Mean	Maximum
Surface soil	0.3	1/356	0	NA	NA	NA	0.20 ± 0.02 pCi/g
Surface vegetation	0.0	0/162	0	NA	NA	NA	NA pCi/g
Surface run-off	0.0	0/237	0	NA	NA	NA	NA pCi/L
Vadose zone (0 to 35 ft)							
Cores	0.0	0/9	0	None	NA	NA	NA pCi/g
Soil moisture	31.6	67/212	65 <sup>d</sup>	PA01, PA02, PA03, W06, W08, W23	1.37 ± 0.19	2.8 ± 0.6	10.2 ± 1.3 pCi/L
Vadose zone (35 to 140 ft)							
Cores	2.4	1/42	0	None	NA	NA	0.115 ± 0.012 pCi/g
Soil moisture	25.0	44/176	27 <sup>d</sup>	D06, I1S, TW1	1.4 ± 0.3	4.6 ± 0.8	17.0 ± 1.5 pCi/L
Vadose zone (140 to 250 ft)							
Cores	4.1	2/48	0	None	0.120 ± 0.013	0.17 ± 0.02	0.21 ± 0.03 pCi/g
Soil moisture and perched water	0.8	1/133	1 <sup>d</sup>	IE6	NA	NA	2.4 ± 0.7 pCi/L
Vadose zone (>250 ft)							
Cores	0.0	0/0	NA	NA	NA	NA	NA pCi/g
Soil moisture	2.7	1/37	1 <sup>d</sup>	R1936	NA	NA	1.9 ± 0.6 pCi/L
Aquifer	2.6	10/385	0	None	0.16 ± 0.02	0.22 ± 0.04	0.30 ± 0.05 pCi/L

a. Ratio = number of detections greater than upper background levels/number of sample analyses.

b. Comparison concentrations (i.e., risk-based concentrations and MCL) are provided in Table 4-1.

c. The following U-235 upper background concentration levels were applied to the various sample media (see Table 4-1):

- 0.103 pCi/g was applied to surface soil, vegetation, and core samples
- 0.61 pCi/L was applied to run-off water and aquifer samples
- 0.15 pCi/L was applied to soil-moisture samples.

d. The value shown is the number of times the isotope contributed to a detection that exceeded the MCL of 30 µg/L for total uranium. Measured U-233/234, U-235/236, and U-238 activities are converted to mass equivalents and combined. If the sum of measured uranium isotopes exceeds the total uranium MCL, each individual isotope is shown as exceeding the MCL.

MCL = maximum contaminant level

Table 4-81. Concentration ranges and detection frequencies of uranium-238 results greater than background levels for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations Above Background <sup>c</sup>		
					Minimum	Mean	Maximum
Surface soil	0.3	1/356	0	NA	NA	NA	1.6 ± 0.3 pCi/g
Surface vegetation	0.0	0/162	0	NA	NA	NA	NA pCi/g
Surface run-off	0.0	0/237	0	NA	NA	NA	NA pCi/L
Vadose zone (0 to 35 ft)							
Cores	7.7	0/13	0	None	NA	NA	NA pCi/g
Soil moisture	70.3	149/212	104 <sup>d</sup>	98-5, PA01, PA02, PA03, W06, W08, W23	3.9 ± 0.7	19.7 ± 2.1	54 ± 5 pCi/L
Vadose zone (35 to 140 ft)							
Cores	6.7	1/45	0	None	NA	NA	0.115 ± 0.012 pCi/g
Soil moisture	40.3	71/176	39 <sup>d</sup>	D06, IIS, R1935, TW1	4.2 ± 0.8	21 ± 2	53 ± 5 pCi/L
Vadose zone (140 to 250 ft)							
Cores	3.9	2/51	0	None	0.120 ± 0.013	0.17 ± 0.02	0.21 ± 0.03 pCi/g
Soil moisture and perched water	6.0	8/133	2 <sup>d</sup>	IE6, R1936	4.3 ± 1.2	9.0 ± 1.3	22 ± 2 pCi/L
Vadose zone (>250 ft)							
Cores	0.0	0/0	NA	NA	NA	NA	NA pCi/g
Soil moisture	16.2	6/37	2 <sup>d</sup>	R1936	4.1 ± 0.8	8.3 ± 1.3	12.4 ± 1.6 pCi/L
Aquifer	0.5	2/385	0	None	1.71 ± 0.16	1.92 ± 0.18	2.1 ± 0.2 pCi/L

a. Ratio = number of detections greater than upper background levels/number of sample analyses.

b. Comparison concentrations (i.e., risk-based concentrations and maximum contaminant levels) are provided in Table 4-1.

c. The following U-238 upper background concentration levels were applied to the various sample media (see Table 4-1):

- 1.40 pCi/g was applied to surface soil, vegetation, and core samples
- 0.90 pCi/L was applied to run-off water and aquifer samples
- 3.68 pCi/L was applied to soil-moisture samples.

d. The value shown is the number of times the isotope contributed to a detection that exceeded the maximum contaminant level of 30 µg/L for total uranium. Measured U-233/234, U-235/236, and U-238 activities are converted to mass equivalents and combined. If the sum of measured uranium isotopes exceeds the total uranium maximum contaminant level, each individual isotope is shown as exceeding the maximum contaminant level.

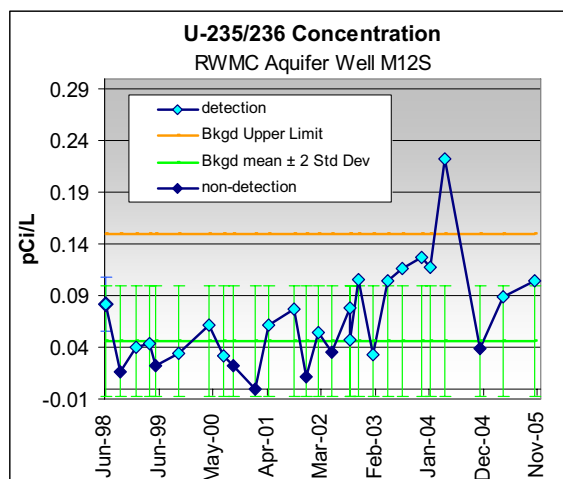


Figure 4-67. Concentration history of U-235/236 at aquifer Well M12S showing data from June 1998.

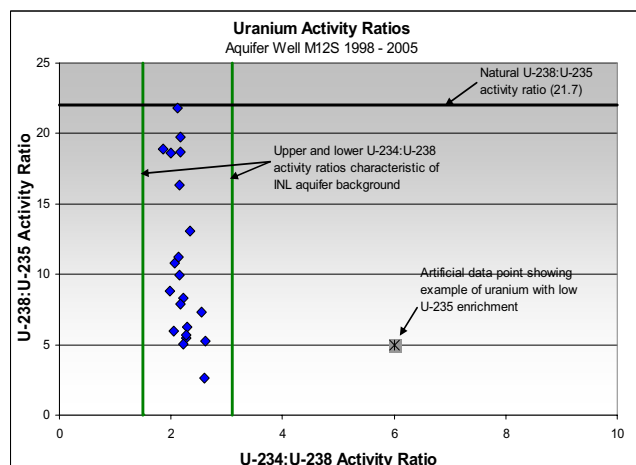


Figure 4-68. Correlation between U-234:U-238 and U-238:U-235 activity ratios showing uranium detected at Well M12S is characteristic of naturally occurring uranium.

#### 4.18.6 Summary of Uranium

Concentrations in all but one location in the vadose zone and aquifer are consistent with naturally occurring uranium, though numerous vadose zone soil-moisture samples significantly exceed local soil-moisture background levels. The one exception, location TW1:DL04 in Pit 5 near Pad A, exhibits concentrations that may be indicative of anthropogenic uranium. Since the latter part of 2002, a gradual concentration trend has been observed at this location, with activity ratios indicating anthropogenic uranium with slight enrichment.

Concentrations exceeding local background levels are most prevalent in shallow and intermediate depths of the vadose zone near three specific areas in the SDA: (1) around Pad A and Pit 5, (2) the western end of the SDA, and (3) the Acid Pit. Though elevated levels of uranium at these locations are within the range of naturally occurring uranium, other contaminants also are detected in these same locations, indicating some migration may be influencing sample results. Figure 4-69 shows the correlation between U-234:U-238 and U-238:U-235 ratios of all lysimeters in the SDA with elevated levels of U-234, U-235, and U-238 since 1997. Historically, three atypical concentrations have been detected—two occurring at location PA02 in 1998 and 1999 and one occurring at location W23:L09 in 1998. Subsequent sample results at these two locations exhibited results characteristic of natural uranium.

Concentrations of uranium detected in aquifer monitoring wells are consistent with natural background values and have never approached or exceeded the MCL for total uranium. The number of detections of U-233/234 and U-238 exceeding the upper background comparison concentrations are consistent with expected rates (i.e., less than or equal to 1%). The detection rate for U-235/236, which is slightly higher than those for U-233/234 and U-238, is attributed to (1) relatively high measurement uncertainties associated with low-level U-235/236 analyses and (2) a low upper background comparison concentration at RWMC (ranges at other aquifer monitoring locations around the INL are typically a factor of two higher than at RWMC).

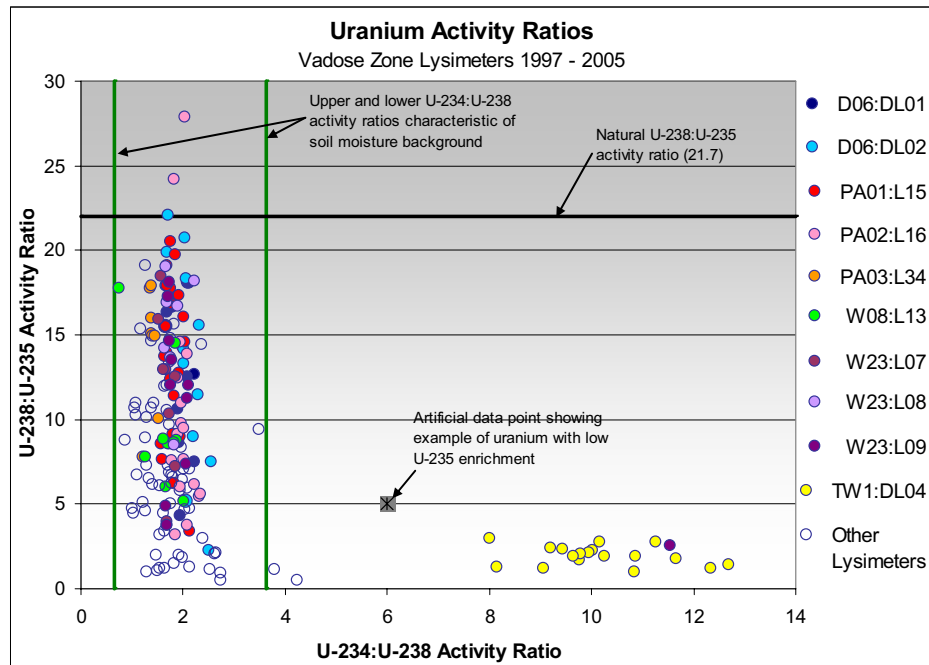


Figure 4-69. Correlation between activity ratios for U-234:U-238 and U-238:U-235.

## 4.19 Nitrate (Inorganic Contaminant)

Nitrate is an inorganic anion generally associated with nitrate-containing salt or fertilizer, or the aerobic decomposition of organic matter. Because it is an anion, nitrate is readily transported through the vadose zone with infiltrating water. Excess nitrate in groundwater is most commonly associated with large-scale farming operations or feedlots (e.g., from the addition of nitrogen-containing fertilizers or from manure in stockpiles or lagoons). Most nitrate in the buried waste originates from nitrate salt produced by weapons manufacturing processes.

Nitrogen is a redox element, and its chemical form in the environment is dependent on the presence or absence of electrons. In reducing environments (e.g., swamps), nitrite is most common; in oxidizing environments, nitrate prevails. Nitrate is the predominant species in RWMC soil, soil moisture, and aquifer samples.

Nitrate sample data are presented in the following tables as they were reported in limitations and validation or laboratory reports (see Section 4.1.6.3). Most data were reported as “nitrate” or “nitrate-N.” The nitrate-N indicates that the concentration obtained by the analysis was reported on a nitrogen basis rather than as nitrate. Nitrate results in this section are compared to the MCL of 10 mg/L. Comparison concentrations are given in Table 4-1. Because sample volumes are generally small and radionuclides have higher analytical priority, nitrate (as nitrogen) analyses are not performed on waste zone soil-moisture samples. Surface soil, vegetation, or run-off water samples also were not analyzed for nitrate.

### 4.19.1 Waste Zone

About  $4.56 \times 10^8$  g of nitrate was buried in the SDA. Most of the nitrate-bearing waste originates from Rocky Flats Plant evaporator salts. Table 4-6 identifies the waste streams containing the nitrate inventory mass. Density of nitrate in buried waste is illustrated in Figure 4-24.

### 4.19.2 Vadose Zone

#### 4.19.2.1 *Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005.*

Three samples (see Section 4.1.4.5) were analyzed for nitrate, which was detected in all three samples. Concentrations varied from 5.3 to 8.9 mg/kg, which are greater than nitrate concentrations observed in SDA soil samples collected at shallow depths in 1993 (0.2 to 2.0 mg/kg) but well below the soil RBC of 438,000 mg/kg.

**4.19.2.2 *Lysimeter Samples at Depths of 0 to 35 ft.*** Between 1994 and August 2004, 126 nitrate analyses were performed on soil-moisture samples collected from 20 shallow vadose zone lysimeters. Of these, 62 sample concentrations exceeded the local soil-moisture upper background of 11.4 mg/L and the MCL of 10 mg/L (see Table 4-82) used for comparison.

Nitrate concentrations in the shallow region of the vadose zone show wide variations, ranging from 0.12 mg/L in Lysimeter W23:L08 to 102 mg/L in Lysimeter W23:L08. Background levels of nitrate in the vadose zone outside the SDA typically range from 0.1 to 11.4 mg/L, with a mean concentration around 2 mg/L. The highest and most consistently detected nitrate concentrations were measured in Well PA02, which is next to Pad A where nitrate-laden waste is buried; in Well W08 near the Acid Pit; and in Well W23 on the western end of the SDA. Nitrate concentrations at Well PA02 showed a sudden and significant increase in FY 2004 (see Figure 4-70), while concentrations at Wells W08 and W23 show no evident trends. Another area where elevated nitrate levels are consistently measured is west of Pit 4 in two adjacent wells (i.e., Wells 98-4 and W-25). Well W25 shows a gradual, steady increase over time (see Figure 4-70).



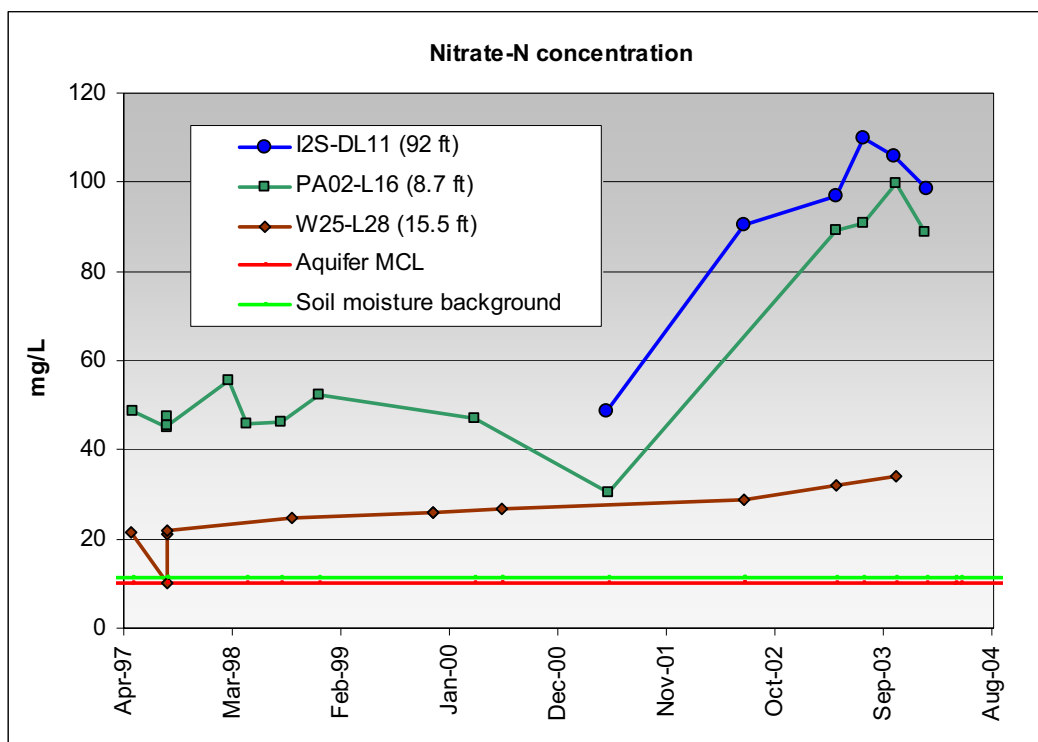


Figure 4-70. Nitrate trends in shallow lysimeters from 1997 through August 2004.

**4.19.2.3 Lysimeter Samples at Depths of 35 to 140 ft.** Between 1995 and August 2004, 71 nitrate and nitrite analyses were performed on soil-moisture samples collected from 14 lysimeters. Of these, 21 sample concentrations exceeded the local soil-moisture upper background of 11.4 mg/L and the MCL of 10 mg/L (see Table 4-82) used for comparison. Similar to results from the shallow vadose zone, nitrate concentrations in the intermediate vadose zone also show wide variations, ranging from 0.1 mg/L in Well O2S to 110 mg/L in Well I2S. Well I2S has the highest nitrate concentration observed in the 35 to 140-ft depth interval. Figure 4-71 illustrates nitrate concentrations over time in Well I2S. Wells monitored around Pad A (i.e., D06, TW1, and I4S) generally have slightly elevated nitrate concentrations in the range of 12 to 32 mg/L. Nitrate concentration in Well I4S shows nitrate contamination has migrated to about the 30-m (100-ft) depth around Pad A. Figure 4-72 illustrates nitrate concentrations over time at this location. This lysimeter well is located in the same vicinity as the high and trending nitrate concentrations observed in shallow Lysimeter PA02 (see above). Figure 4-73 illustrates nitrate concentrations over time at Lysimeter D06:DL02 (44 ft). Nitrate has not been detected at the 88-ft depth (Lysimeter D06:DL01).

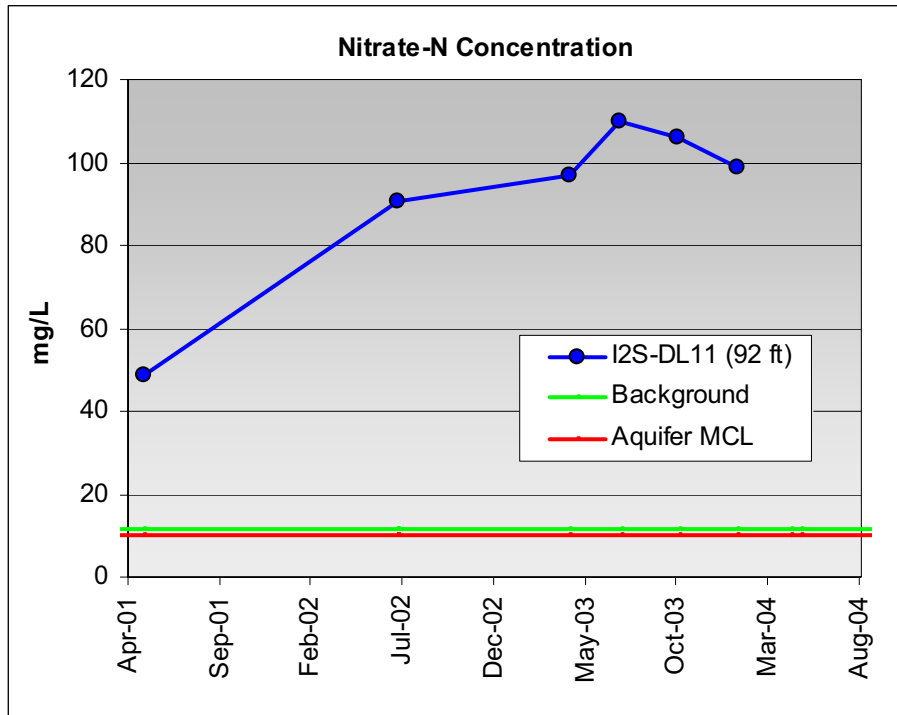


Figure 4-71. Lysimeter nitrate concentration over time at the western end of the Subsurface Disposal Area in the 35 to 140-ft depth interval.

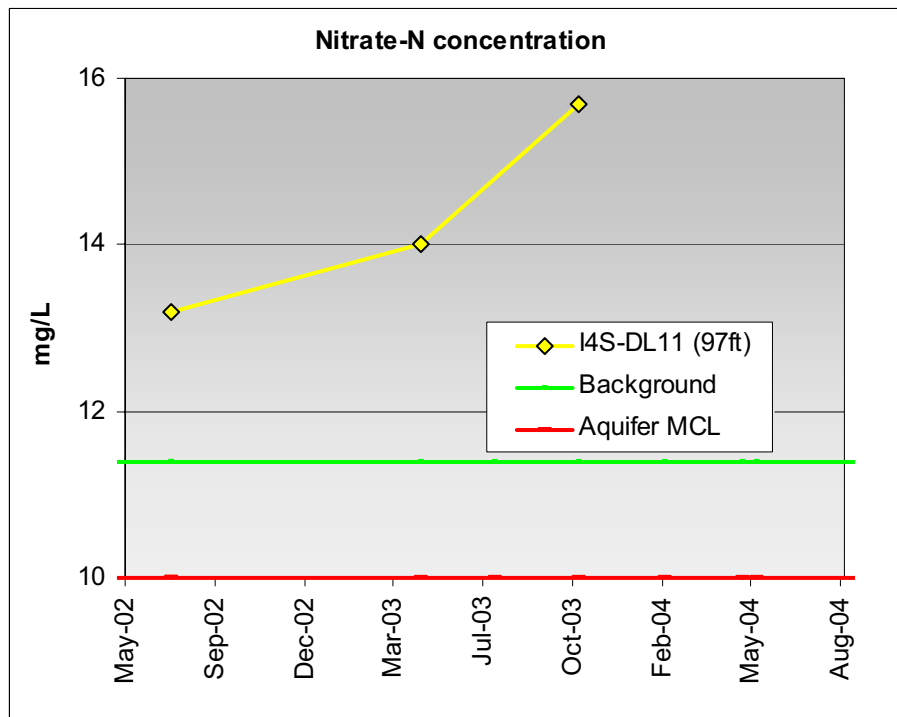


Figure 4-72. Lysimeter nitrate concentration over time beneath Pad A at the 97-ft depth.

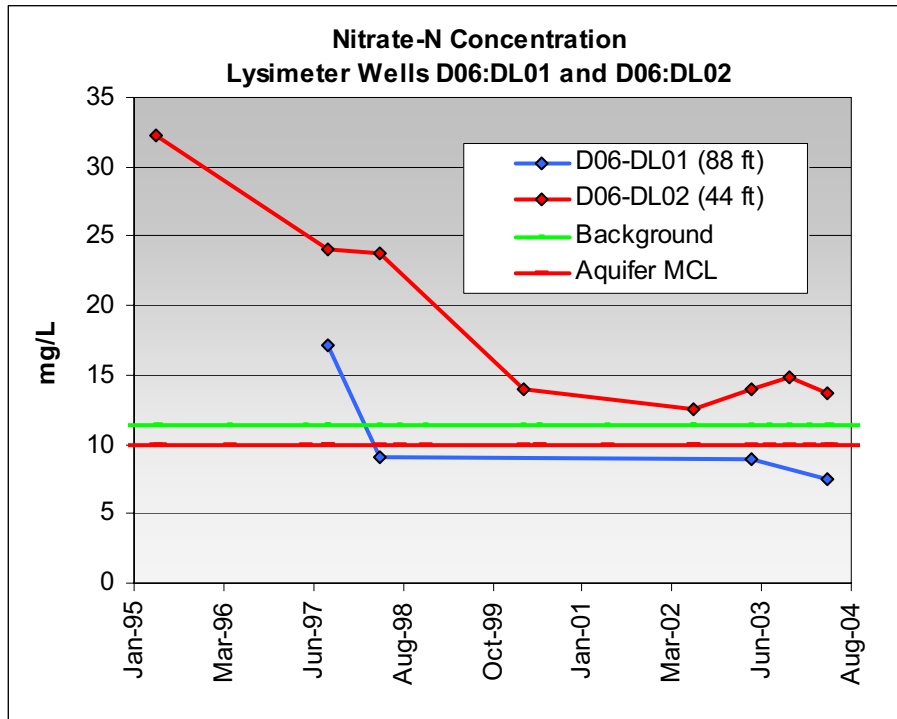


Figure 4-73. Lysimeter nitrate concentrations over time beneath Pad A at 44 and 88 ft.

**4.19.2.4 Lysimeter Samples at Depths Greater Than 140 ft.** Between 1992 and May 2004, 58 nitrate (as nitrogen) analyses were performed on samples collected from 18 lysimeters and four perched water wells near RWMC, with two perched water results above aquifer background and one lysimeter slightly above local soil-moisture background. Nitrate concentrations in this depth interval range from 0.10 to 11.6 mg/L. The concentrations in the deep vadose zone soil moisture and perched water are near background levels and exhibit much less variation than do nitrate concentrations in the shallow and intermediate vadose zone. Figure 4-74 illustrates nitrate levels in perched water at Well USGS-92.

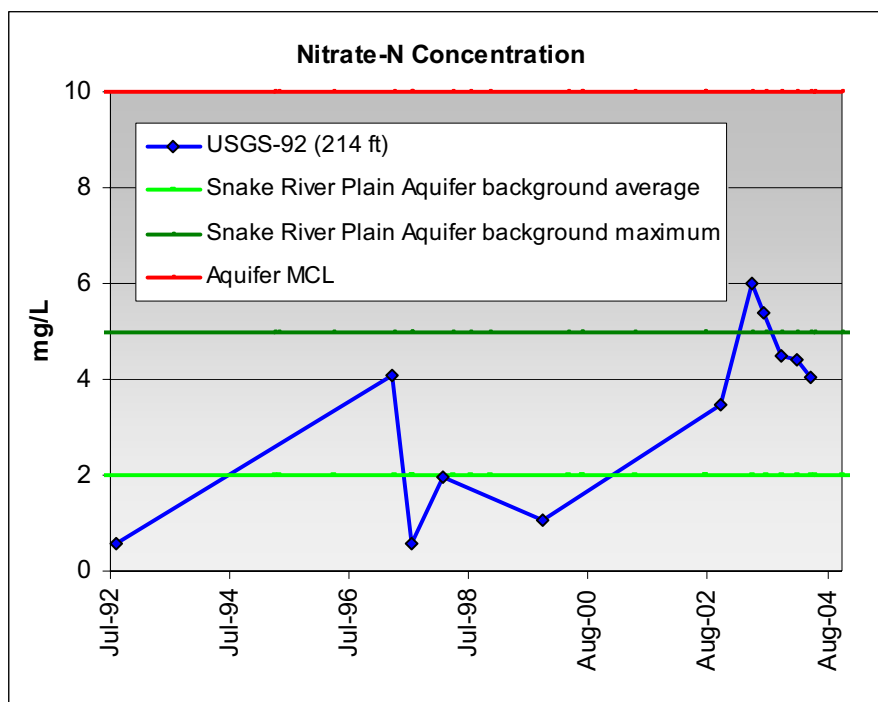


Figure 4-74. Nitrate concentrations over time in samples from perched water Well USGS-92.

**4.19.2.5 Vadose Zone Core Samples.** During the 1993 investigation, 54 nitrate and nitrite analyses were performed on core samples, 27 of which yielded positive detections (see Table 4-82). Detected concentrations ranged from 0.2 to 3.0 mg/L, with no apparent relationship with sampling depth and were all well below the soil RBC of 438,000 mg/kg.

### 4.19.3 Aquifer

Between 1992 and May 2004, 468 nitrate (as nitrogen) analyses were performed on samples collected from 16 RWMC monitoring wells around RWMC. All INL RWMC wells sampled from 1992 to May 2004 had nitrate concentrations below the MCLs and were characteristic of levels normally detected in the Snake River Plain Aquifer, except for 12 results that exceeded the typical background range of 2 mg/L. Reported levels of nitrate typically found in the Snake River Plain Aquifer are 1 to 2 mg/L, with concentrations ranging from 0.4 to 5 mg/L (Knobel, Orr, and Cecil 1992). The range of concentrations associated with RWMC aquifer monitoring wells from 1992 to May 2004 varied from a minimum of 0.28 mg/L to a maximum of 3.4 mg/L, with a mean concentration of 0.87 mg/L. Concentrations in all RWMC monitoring wells were less than 2.0 mg/L, except for Well M6S. Concentrations in Well M6S are slightly higher than all other RWMC monitoring wells and have been gradually increasing since 1992 (see Figure 4-75), with the most notable changes occurring after 1999; however, all detected concentrations in this well have been less than the 5-mg/L upper background range, and the trend appears to have stabilized since 2002.

In the last quarter of FY 2004, the frequency at which the aquifer near RWMC was monitored changed from quarterly to biannually; therefore, data from three quarters were obtained in FY 2004.

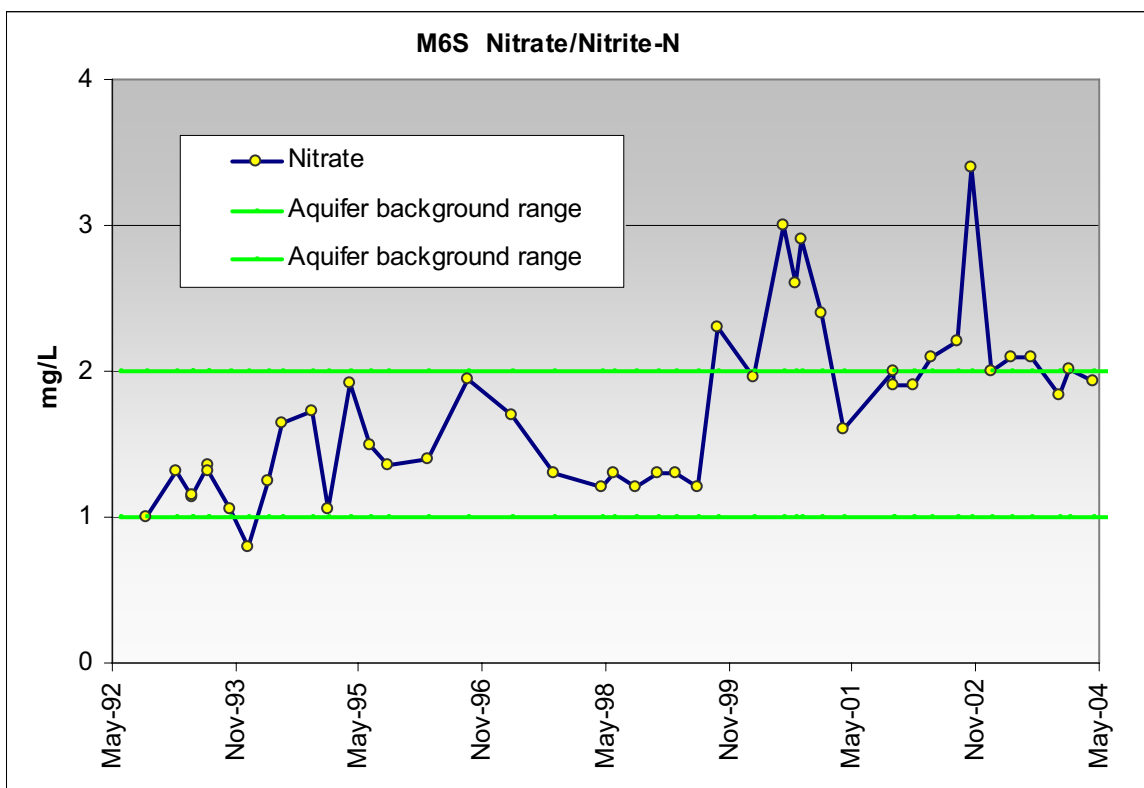


Figure 4-75. Concentration of nitrate (as nitrogen) in Radioactive Waste Management Complex aquifer monitoring Well M6S from 1992 to May 2004.

#### 4.19.4 Summary of Nitrate

Nitrate concentration trends are apparent at some lysimeter monitoring locations in the vadose zone. Significant concentration trends were associated with Lysimeters PA02:L16 and I2S:DL11, providing evidence that nitrate has migrated to about 30 m (100 ft) in the vadose zone. Nitrate concentrations are highest in the 0 to 35-ft and 35 to 140-ft regions of the vadose zone, and are most prevalent in lysimeter wells located around the Pad A area (i.e., Wells D06, I4S, PA01, PA02, and TW1), the western end of the SDA (i.e., Well I2S), and the western end of Pit 4 (i.e., Wells 98-4 and W25).

Nitrate concentrations in soil and core materials are low, ranging from 0.2 to about 9 mg/kg, which is well below the soil RBC of 438,000 mg/kg used for comparison. No apparent temporal or spatial relationship has been observed.

Low levels of nitrate were detected in all aquifer monitoring wells at concentrations characteristic of Snake River Plain Aquifer background. Though aquifer Well M6S exhibited trending nitrate concentrations slightly higher than all other RWMC monitoring wells, concentrations never exceeded the upper background range. The trend appears to have stabilized below background.

Table 4-82. Nitrate detection frequencies for concentrations greater than background for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentrations	Range of Detected Concentrations Above Background <sup>c</sup>		
					Minimum	Mean	Maximum
Vadose zone (0 to 35 ft)							
Cores	44.4	4/9	0	None	0.21	0.78	1.96
Soil moisture	43.7	55/126	55	98-4, 98-5, D15, PA01, PA02, PA03, W05, W08, W23, W25	13	40	102
Vadose zone (35 to 140 ft)							
Cores	56.0	14/25	0	None	0.23	0.57	1.86
Soil moisture	29.6	21/71	21	D06, I-2S, I-4S, TW1	12	37	110
Vadose zone (140 to 250 ft)							
Cores	45.0	9/20	0	None	0.22	0.75	2.94
Soil moisture and perched water	6.1	3/49	3	I-2D, USGS-92	5.4	7.7	11.6
Vadose zone (>250 ft)							
Cores	NA	NA	0	NA	NA	NA	NA
Soil moisture	0.0	0/9	0	NA	NA	NA	NA
Aquifer	2.6	12/468	0	None	0.28	0.87	3.4

a. Ratio = number of detections/number of sample analyses.

b. Table 4-1 provides comparison concentrations (i.e., risk-based concentrations for soil and maximum contaminant levels for water).

c. Nitrate upper background concentrations listed below were applied to the various sample media (see Table 4-1):

- 0.0 mg/kg was applied to core samples
- 5.0 mg/L was applied to aquifer samples
- 11.4 mol/L was applied to soil moisture samples

a. Ratio = number of detections/number of sample analyses.

b. Table 4-1 provides comparison concentrations (i.e., risk-based concentrations for soil and maximum contaminant levels for water).

c. Nitrate upper background concentrations listed below were applied to the various sample media (see Table 4-1):

- 0.0 mg/kg was applied to core samples
- 5.0 mg/L was applied to aquifer samples
- 11.4 mg/L was applied to soil-moisture samples.

## 4.20 Chromium

Chromium is not a contaminant of potential concern for this RI/BRA, as demonstrated in the Interim Risk Assessment (Becker et al. 1998; DOE-ID 1998); however, because measured values of chromium in the aquifer beneath RWMC are available for comparison against predicted values, it serves as a useful modeling performance indicator. Therefore, the nature and extent of chromium associated with the SDA are described in the following subsections.

Chromium is a naturally occurring metallic element found in water, soil, and rock. Chromium has various industrial uses, such as hardening steel, fabricating various alloys, electroplating, leather tanning, and corrosion protection. Under natural conditions, chromium is present primarily as chromium(III) and, depending on environmental conditions, also can be present in smaller amounts as chromium(VI) (Ball and Izbicki 2004). Chromium(III) is fairly insoluble and has a low toxicity, whereas chromium(VI) is very soluble and has a higher toxicity. Although some chromium(VI) is produced naturally in the environment, most is the result of human activities. Chromium in the aquifer around RWMC may be the result of (1) historical operations at RTC and INTEC, (2) SDA waste leachates, (3) corrosion of well construction materials, or (4) high natural abundance of chromium in basaltic formations beneath RWMC.

Historically, chromium was used primarily at the INL Site as a corrosion inhibitor for cooling tower operations. (Note that in 1972, chromium was replaced by a polyphosphate.) Chromium also is naturally occurring in the Snake River Plain Aquifer as a component of basaltic magmas. Most chromium buried in the SDA came from Rocky Flats Plant in the chemical form of chromate salts.

Concentrations of dissolved chromium in the Snake River Plain Aquifer, upgradient and downgradient of the INL Site, range from 1 to 50 µg/L (Knobel, Orr, and Cecil 1992), whereas concentrations on or near the INL Site range from 1 to 190 µg/L, with the highest concentrations near RTC (Knobel et al. 1999). Excluding RTC data, chromium concentrations on or near the INL Site are typically around 7 µg/L, but range from 1 to 22 µg/L. Comparison concentrations for chromium are given in Table 4-1. Waste zone, surface soil, vegetation, and run-off water samples are not analyzed for chromium.

### 4.20.1 Waste Zone

About 2.32E+06 g of chromium was buried in the SDA. All of the chromium in the SDA is associated with Rocky Flats Plant evaporator salt (see Table 4-6).

### 4.20.2 Vadose Zone

Distributions of chromium in vadose zone cores, soil moisture, and perched water in various depth intervals are discussed below.

**4.20.2.1 Lysimeter Samples at Depths of 0 to 35 ft.** Between 1996 and August 2004, 58 chromium analyses were performed on soil-moisture samples collected from seven shallow lysimeters near RWMC, with 19 results above the upper background concentration range of 13 µg/L. None of the results exceeded the MCL of 100 µg/L used for comparison. Concentrations in this depth interval ranged from 13.4 µg/L to 39 µg/L and were associated with lysimeter monitoring wells located at the western end of the SDA (W23 and 98-5), the Acid Pit (W08), and southeastern corner of the SDA (98-1). Detections above the upper background range occur most frequently at Wells W23 and 98-5 and are sporadic at other lysimeter locations. Concentration trends are not evident at any monitoring location in the shallow region of the RWMC vadose zone.

**4.20.2.2 Lysimeter Samples at Depths of 35 to 140 ft.** Between April 2003 and August 2004, 48 chromium analyses were performed on soil-moisture samples collected from 13 intermediate-depth lysimeters near RWMC, with four results above the upper background concentration range of 13 µg/L. Three of the four results exceeded the MCL of 100 µg/L used for comparison, with two being anomalously high (i.e., 32,400 and 43,200 µg/L) and very questionable because they occurred in samples from lysimeter wells outside RWMC (O-2 and O-4). Concentrations at the other two wells (I-2S and I-4S) were more plausible at 15.1 µg/L and 116 µg/L, respectively. Subsequent samples collected from Wells I-2S and I-4S showed chromium concentrations more consistent with local soil-moisture background. One subsequent sample has been collected from Well O-2, and the chromium concentration was 370 µg/L, which is dramatically lower than the previous result of 32,400 µg/L. Other samples have yet to be collected from Well O-4 and analyzed for chromium; however, the high concentration of 43,200 µg/L is most likely an analytical anomaly. Consistent detections or observable concentration trends are not evident at any monitoring locations in the intermediate-depth region of the vadose zone.

**4.20.2.3 Lysimeter Samples at Depths Greater Than 140 ft.** Between April 2003 and August 2004, 40 chromium analyses were performed on soil-moisture and perched water samples collected from 11 lysimeters and three perched water wells, with 17 results above the upper background concentration range of 13 µg/L. Six detections were greater than the 100-µg/L MCL used for comparison. Concentrations in this depth interval ranged from 14.3 µg/L to 3,550 µg/L, with the highest concentrations obtained in monitoring locations outside RWMC (i.e., O-2:DL19 and O-7:DL27). Lysimeter O-7:DL27, located approximately 0.4 km (0.25 mi) southwest of the SDA, has a history of high-chromium results that range from 1,180 to 1,300 µg/L. The high chromium is likely from corrosion of well construction materials because cobalt, iron, manganese, and nickel concentrations at this location are also high. The chromium concentration at Lysimeter O-2:DL19 was 3,550 µg/L, and like O-7:DL27, cobalt, iron, manganese, and nickel are also high, indicating possible corrosion of well construction materials. This metal does not appear to be suspended solids from natural rock materials. The geochemical behaviors of iron, chromium, and nickel are very different. Iron has a higher solubility at low redox potential, chromium is higher in solubility at high redox potential, and nickel is not affected by redox potential. Therefore, the metal does not appear to be related to geochemical conditions in the vadose zone. The ratio of iron to chromium to nickel in this water sample is typical of the ratio of the same metal in stainless steel. Elevated metal in samples from Lysimeters O-2 and O-7 is probably the result of stainless steel from lysimeter material suspended in the sample that was dissolved during sample digestion. Most other monitoring wells with elevated chromium are first-time detections that occurred in May 2004, and most results are accompanied by other elevated metal concentrations. Widespread chromium is not indicated in deep regions of the vadose zone beneath RWMC; however, analytical data appear to be more indicative of corrosion or deterioration of lysimeter well construction material.

**4.20.2.4 Vadose Zone Core Samples.** Fifty-four chromium analyses were performed on core samples from the 1993 investigation, 16 of which exceeded the surficial soil upper background concentration tolerance limit of 33 mg/kg (see Table 4-1). Concentrations ranged from 9 to 72 mg/kg and averaged about 27 mg/kg, which is consistent with surficial soil background.



### 4.20.3 Aquifer

Between 1992 and May 2004, 557 chromium analyses were performed on aquifer samples collected from 16 RWMC aquifer monitoring wells, with 140 results above the INL Site upper background concentration range of 22 µg/L. Many chromium concentrations in the aquifer beneath RWMC are significantly above the maximum concentration range found in the Snake River Plain aquifer around the INL Site. Total chromium concentrations range from 2.6 µg/L in Well M4D to 130 µg/L in Well M16S. Total chromium includes contributions from dissolved and solid chromium as well as chromium in various oxidation states (e.g., Cr<sup>3+</sup> and Cr<sup>6+</sup>). Total chromium concentrations in four RWMC monitoring wells (i.e., Wells M1SA, M6S, M11S, and M15S) historically exceed concentrations typically detected in the Snake River Plain Aquifer around the INL Site (1 to 22 µg/L), as determined from data published by Knobel et al. (1999), which excludes atypically high concentrations measured around RTC. Wells M1SA and M6S have shown a gradually increasing concentration trend over the past 11 years, and Wells M11S and M15S began their upward trend in the past couple of years (see Figure 4-76).

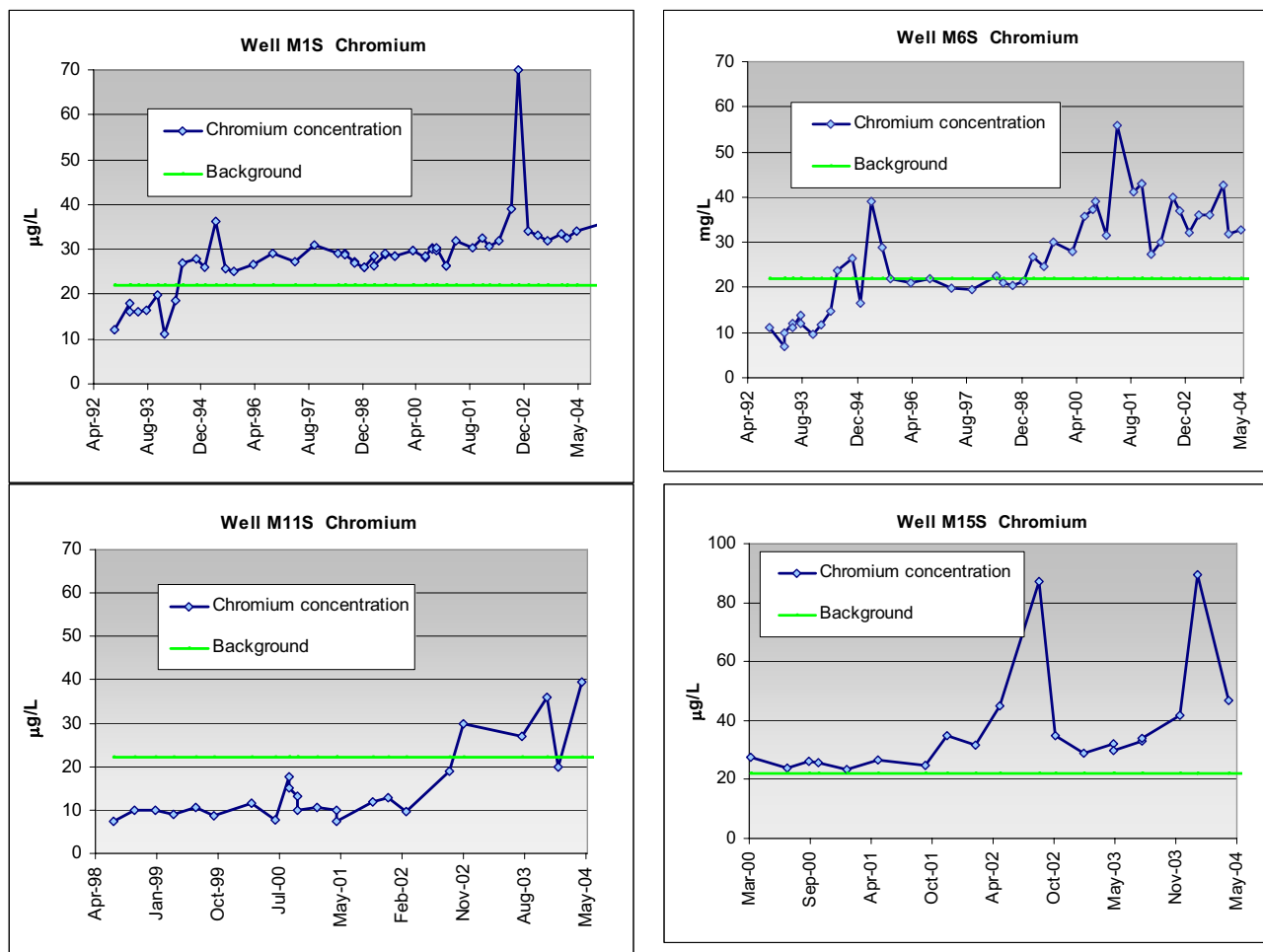


Figure 4-76. Radioactive Waste Management Complex aquifer monitoring wells with increasing chromium concentrations.

The USGS monitoring wells south of RWMC (Wells USGS-88, USGS-89, and USGS-119) also have elevated concentrations of chromium. Even though Wells USGS-088, USGS-089, and USGS-119 have not been analyzed recently for chromium (1996 is most recent), chromium levels in those wells probably are elevated and roughly comparable to those measured in the Waste Area Group 7 aquifer monitoring wells located on the southern and southeastern side of RWMC. Most wells with elevated chromium concentrations are located immediately south and southeast of RWMC, except for Well M11S, which is about 3 km (2 mi) upgradient of RWMC. This pattern of chromium occurrence is consistent with other elevated analytes (i.e., bromide, chloride, magnesium, sodium, and sulfate) in these particular wells; this would be expected if constituents were leaching from the SDA and migrating to the south and southeast because of the presence of a low-flow or low-permeability zone (Wylie and Hubbell 1994).

The USGS has analyzed many RWMC groundwater samples for total chromium, dissolved chromium, and hexavalent chromium. Their data show a significant fraction of chromium is in the dissolved phase (approximately 75%), and of that fraction, about 65% is chromium(VI). Therefore, a substantial amount of chromium in RWMC aquifer appears to be anthropogenic. Basaltic formations located beneath RWMC possibly could contain substantial amounts of chromium(VI), as recently discovered in basalts beneath the Mohave Desert by USGS (Ball and Izbicki 2004).

Chromium in Well M11S contains a significant fraction of suspended solids, indicating that chromium in this well is likely to be associated with corrosion of stainless steel well construction materials. Chromium in Wells M1SA, M6S, and M15S is mostly in the dissolved phase, indicating chromium could be from high natural abundance in basaltic formations beneath RWMC or from the SDA waste leachates. Well M15S also has a substantial fraction of chromium that exists as a suspended solid, suggesting corrosion of well construction materials.

Concentrations of dissolved chromium in the Snake River Plain Aquifer, upgradient and downgradient of the INL Site, range from 1 to 50  $\mu\text{g/L}$  (Knobel, Orr, and Cecil 1992), whereas concentrations on or near the INL Site range from 1 to 190  $\mu\text{g/L}$ , with the highest concentrations near RTC (Knobel et al. 1999). Whether elevated levels of chromium in wells located at the south-southeastern side of RWMC are from the SDA, RTC, or natural occurrences has not been absolutely determined. Chromium concentrations within a 2-km (1-mi) radius of RWMC are generally higher than concentrations farther away than 2 km (1 mi) (see Figure 4-77).

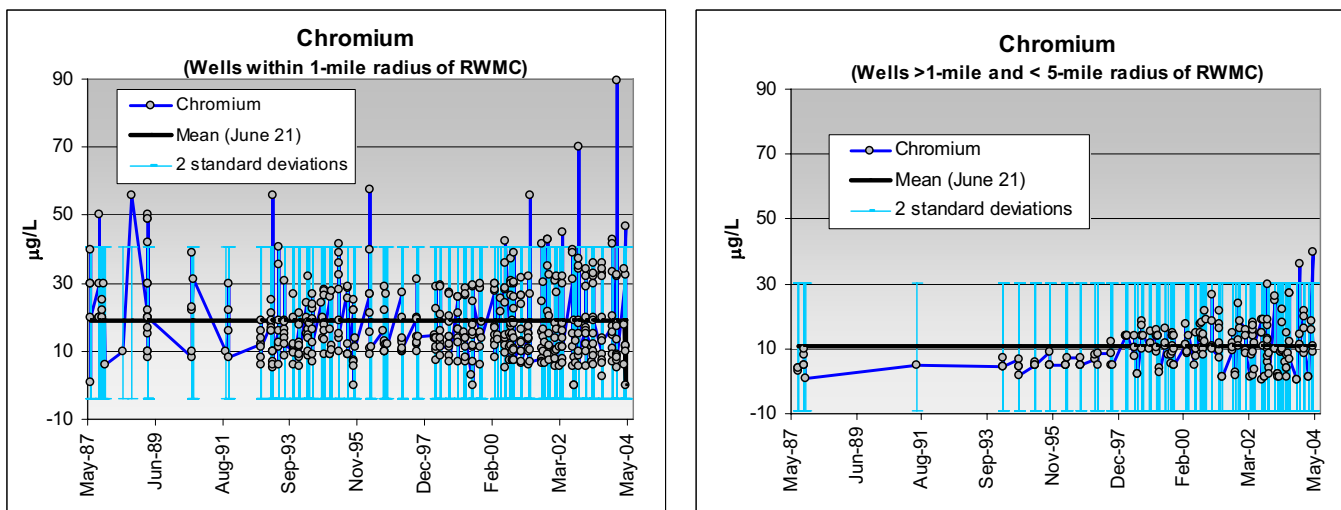


Figure 4-77. Chromium concentrations within a 1-mi radius are generally higher than concentrations within a 1 to 5-mi radius of the Radioactive Waste Management Complex.

#### **4.20.4 Summary of Chromium**

Consistent detections or observable concentration trends are not evident at any monitoring locations in the shallow, intermediate, or deep regions of the vadose zone. Also, widespread chromium is not observed in the vadose zone beneath RWMC. Many of the analytical data are indicative of corrosion or deterioration of lysimeter well construction materials (see Table 4-83).

Chromium concentrations in most RWMC aquifer monitoring wells are consistent with levels typically observed around the INL Site (i.e., 1-22 µg/L) (see Figure 4-78), with chromium concentrations in Wells M1S, M6S, M11S, and M15S above the Snake River Plain Aquifer background at the INL Site and increasing. Elevated levels of chromium in the aquifer around RWMC could be natural phenomena. Alternatively, these concentrations might be attributable to groundwater contaminants from RTC or INTEC, leachates from buried waste, or corrosion of well construction materials.

Table 4-83. Chromium detection frequencies of concentrations greater than background for sampled media.

Sample Media	Detection Rate (%)	Ratio <sup>a</sup>	Number of Detections Greater Than Comparison Concentrations <sup>b</sup>	Wells with Detections Greater Than Comparison Concentration	Range of Detected Concentrations Above Background <sup>c</sup>		
					Minimum	Mean	Maximum
Vadose zone (0 to 35 ft)							
Cores	33.3	3/9	NA	NA	33.6	34.4	35.5 mg/kg
Soil moisture	32.2	19/59	0	None	13.4	25.6	39.0 μg/L
Vadose zone (35 to 140 ft)							
Cores	12.0	3/25	NA	NA	34.0	56.9	71.6 mg/kg
Soil moisture	8.3	4/48	3	I-4S, O-2, O-4	15.1	18,933	43,200 μg/L
Vadose zone (140 to 250 ft)							
Cores	50.0	10/20	NA	NA	34.1	40.2	55.5 mg/kg
Soil moisture and perched water	53.3	16/30	6	D-10, I-2D, O-7	14	494	3,550 μg/L
Vadose zone (>250 ft)							
Cores	NA	NA	NA	NA	NA	NA	mg/kg
Soil moisture	20.0	2/10	0	None	27.4	29.6	29.6 μg/L
Aquifer	25.1	140/557	1	M16S	22.3	33.5	33.5 μg/L

a. Ratio = number of detections/number of sample analysis.

b. Table 4-1 provides comparison concentrations (i.e., risk-based concentrations for soil and maximum contaminant levels for water).

c. Chromium upper background concentrations listed below were applied to the various sample media (see Table 4-1):

- 33 mg/kg was applied to core samples
- 22 μg/L was applied to aquifer samples
- 13 μg/L was applied to soil-moisture samples

a. Ratio = number of detections/number of sample analysis.

b. Table 4-1 provides comparison concentrations (i.e., risk-based concentrations for soil and maximum contaminant levels for water).

c. Chromium upper background concentrations listed below were applied to the various sample media (see Table 4-1):

- 33 mg/kg was applied to core samples
- 22 µg/L was applied to aquifer samples
- 13 µg/L was applied to soil-moisture samples.

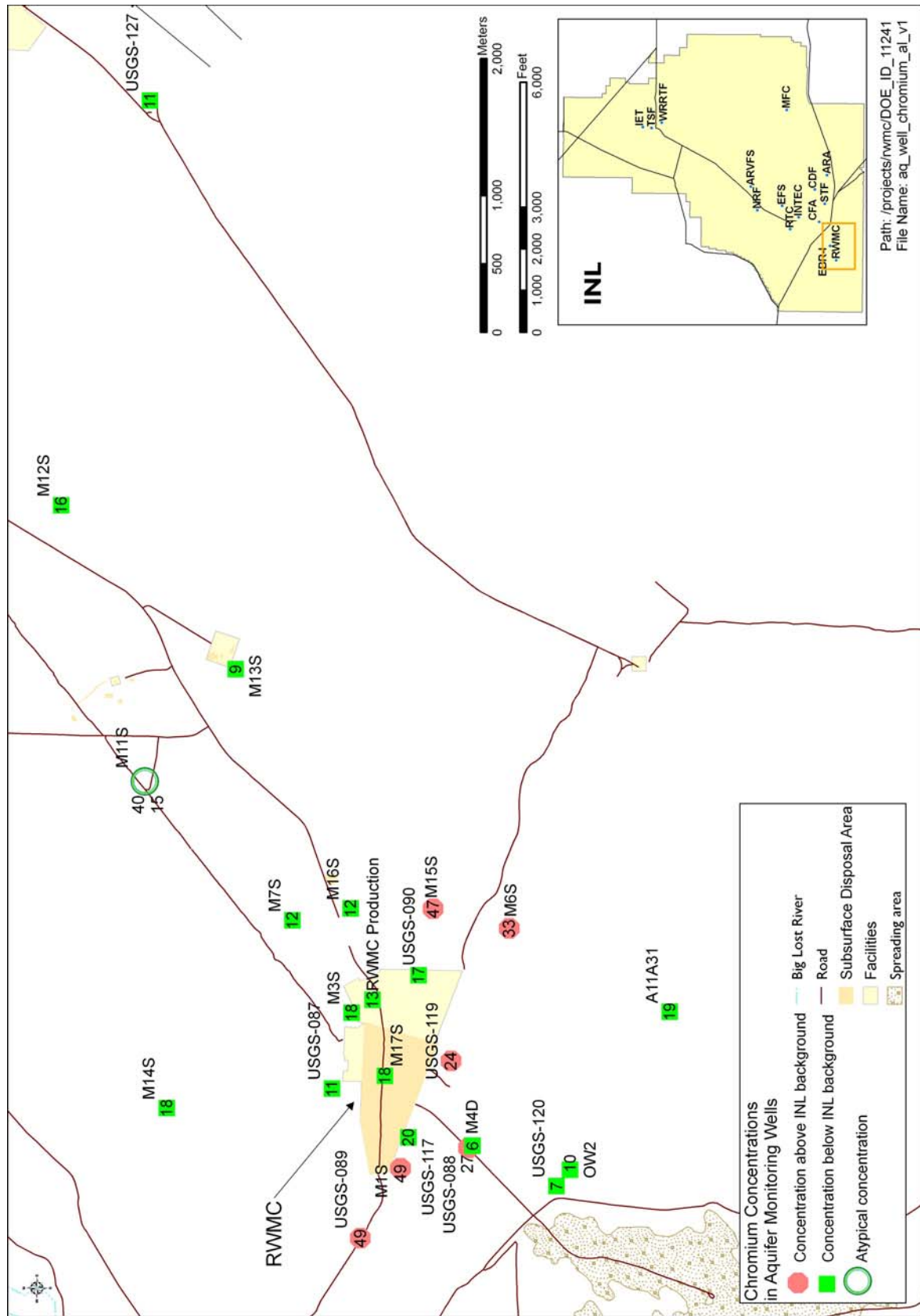


Figure 4-78. Chromium concentrations in wells at the Radioactive Waste Management Complex.

## 4.21 Other Inorganic Contaminants

Numerous anions and metals are routinely monitored even though these constituents are not contaminants of potential concern. Anion and metal contaminants detected in the vadose zone have relatively high concentrations, and many are attributed to magnesium chloride brine applied to suppress dust on SDA roads in 1984, 1985, 1992, and 1993. Chemical constituents of the brine are now widely distributed in the vadose zone at RWMC, and most elevated concentrations of cations and anions can be related to the brine application. The primary anion in brine is chloride, but bromide and sulfate also are present at high concentrations. Elevated calcium, sodium, potassium, and magnesium also are related to brine application. Brine affects the chemistry of soil water by ion exchange, as evidenced by elevated brine constituents and changes in anion ratios. Higher mineral content and altered chemistry of the soil water accelerate migration of some waste contaminants. Because chemical constituents of brine are corrosive, they likely have contributed to premature corrosion and deterioration of waste containers in the SDA.

Brine constituents are consistently detected during routine monitoring of vadose zone soil moisture to depths around 30 m (100 ft), with sporadic detections at depths around 67 m (220 ft). Hull and Bishop (2003) concluded that brine has definitely migrated at least 73 m (240 ft) deep at RWMC since 1984, and can move laterally. Vertical migration rates of 6 to 40 m (20 to 130 ft) per year were estimated for brine constituents (Hull and Bishop 2003), and, at this rate, brine constituents could have reached the aquifer by now. Though routinely detected, chemical constituents of brine generally are not reported unless concentrations begin to increase or change suddenly, or constituents are detected at deeper depths. Lysimeter and aquifer results for other inorganic contaminants are addressed in the following sections.

### 4.21.1 Vadose Zone

Because of the large number of reportable inorganic analysis results, a table listing each result for each lysimeter for each quarter is not included in this RI/BRA.<sup>a</sup> Table 4-84 lists analytes detected above local soil-moisture background and associated concentration ranges observed since 1992.

Some high metal concentrations show uncharacteristic and abrupt increases over the years; however, in many cases, subsequent sample results show concentrations have returned to normal.

Selenium is often detected above local soil-moisture background concentrations in various lysimeter samples. Concentrations of barium, iron, and manganese in deep lysimeter Well DE7 are significantly above local soil-moisture background and increasing. These analytes are naturally occurring and are mentioned only because previous samples collected from this lysimeter well were discolored and had an unidentifiable organic odor. A relationship may exist between elevated cation concentrations and unidentified VOCs.

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b. Reportable inorganic analysis results are reported in Operable Unit 7-13/14 quarterly reports to DOE-ID.

Table 4-84. Anions and metal with concentrations above background in Subsurface Disposal Area vadose zone soil moisture (lysimeter) and perched water.

Analyte	Sample Concentration Range (mg/L)	Local Soil-Moisture Background <sup>a</sup> (mg/L)	Wells with Highest Concentration <sup>b</sup>	Wells with Most Detections above Background <sup>b</sup>
Aluminum	0.142 to 11.0	0.140	USGS-92 (PW)	USGS-92(PW)
Antimony	0.031 to 1.06	0.031	O-2	None
Arsenic	0.045 to 0.79	0.040	O-2	W23
Barium	0.167 to 0.87	0.150	DE7	DE7, W25
Bromide	2.16 to 21.0	2.00	98-1	D06, DE7, I-1S, PA02, TW1, USGS-92(PW), 8802D(PW), 98-1
Cadmium	0.005 to 0.17	0.003	O-4	None
Calcium	181 to 1,800	180	I-1S	D06, DE7, I-1S, TW1, USGS-92(PW), 8802D(PW), 98-1
Chloride	362 to 9,566	340	98-1	D06, DE7, I-1S, I-4S, PA02, TW1, USGS-92(PW), 8802D(PW), 98-1,
Chromium	0.014 to 43.2	0.013	O-4	W23, 98-5, O-7
Cobalt	0.008 to 1.09	0.004	O-4	D06
Copper	0.242 to 0.882	0.190	O-2	None
Fluoride	2.45 to 5.74	2.00	PA01	PA01
Iron	0.262 to 471	0.210	IE7	DE7, O-7, USGS-92(PW), IE6
Lead	0.016 to 0.190	0.016	USGS-92 (PW)	None
Magnesium	69.8 to 655	64.1	I-1S	D06, DE7, I-1S, PA02, TW1, USGS-92(PW), 8802D(PW), 98-1
Manganese	1.17 to 17.3	0.99	O-4	DE7
Nickel	0.223 to 68.2	0.17	O-2	O-7
Nitrate-N	11.6 to 129	11.4	D06	D06, I-2S, I-4S, PA01, PA02, TW1, W08, W25, 98-4
Potassium	19.7 to 2,650	18.8	D-10(PW)	DE4, D06, I-1S, TW1, USGS-92(PW), 8802D(PW),
Selenium	0.020 to 0.17	0.020	I-1S	D06, PA01
Silver	0.008 to 0.054	0.006	O-2	None
Sodium	391 to 3,200	390	D06	D06, I-1S, IE6, PA01, PA02, TW1, USGS-92(PW), W05, W23, 8802D(PW), 98-1
Sulfate	603 to 8,700	596	I-2D	D06, IE6, O-2S, USGS-92(PW), 8802D(PW), 98-1
Vanadium	0.0274 to 0.101	0.027	O-4	PA01

a. From Koeppen et al. (2005).

b. PW = perched water well; all other wells are lysimeters.

#### 4.21.2 Magnesium Chloride Brine

Lysimeter wells with evidence of brine contamination are consistent with wells where brine was previously identified (Hull and Bishop 2003). Brine contamination also was detected in Well D15 outside RWMC and in Wells DE7 and IE7, which were installed in 2003. Wells 98-1 and PA02 have the highest measured chloride concentrations, along with other brine constituents, in the shallow vadose zone with up to 11,000 mg/L. Well 98-1 is located in the southeastern corner of the SDA, and Well PA02 is located next to Pad A. Chloride levels in the intermediate vadose zone have reached 5,300 mg/L in Well I-1S. Two perched water wells and two lysimeter wells (i.e., Wells 8802D, USGS-92, DE7, and I-4D) in the deep region of the vadose zone show chloride levels about 90 to 800 mg/L, which are above the perched water background concentration of 21 mg/L and soil-moisture background of 340 mg/L. Evidence from Lysimeters DE7:DL36 and DE7:DL37 indicates brine has migrated to 115 and 126 m (377 and 413 ft). The chloride concentration at three of these deep locations is greater than 350 mg/L, and the chloride:bromide concentration ratios are around 400:1, indicating the constituents at these depths are attributable to magnesium chloride brine. Some evidence also suggests the brine may be responsible for some of the elevated anion and cation concentrations in the Snake River Plain Aquifer beneath RWMC (see Figure 5-4).

#### 4.21.3 Aquifer

Several anions and cations have been detected in concentrations greater than aquifer background values over the years. Lead-analysis results of one sample collected from Well A11A31 in January 2004 exceeded the MCL. Historically, elemental lead has been detected sporadically in this well and is likely to be associated with corrosion of the well casing, which is constructed of galvanized steel. Corrosion of the galvanized steel casing also explains why concentrations of aluminum, iron, and zinc are elevated in this well because they are all components of galvanized steel.

Elevated concentrations of aluminum, chromium, iron, magnesium, and sodium are the most widespread and frequently detected metal in the aquifer. Frequently detected anions are bromide, chloride, and sulfate. Other metals and anions were detected above aquifer background concentrations but are not widespread and appear unique to some monitoring wells (e.g., arsenic and fluoride are primarily detected in Well M4D, and lead and zinc are mostly associated with Well A11A31). Analytes with historical concentrations above aquifer background levels and their associated concentration ranges are listed in Table 4-85. Most concentrations show no observable concentration trends; however, very evident concentration trends (not shown) are occurring at some well locations south-southeast of RWMC. Sodium concentrations have been steadily increasing in most RWMC aquifer wells but are decreasing in Wells A11A31 and USGS-88. Chloride, sodium, and sulfate concentrations are decreasing at fairly significant rates at Well A11A31. Sulfates also are decreasing in neighboring Well OW2. Chloride and sodium are decreasing at Well USGS-88, while sulfate concentrations remain high and stable. Chloride in Well USGS-120 is decreasing gradually, while sodium and sulfate concentrations exhibit cyclical trends that appear to oscillate concurrently. Anion and cation data may be providing clues to understanding transport through the vadose zone and groundwater beneath RWMC.

Many of these anions and metals appear to be characteristic of magnesium chloride brine, though buried waste or concentrations in groundwater from RTC (e.g., sulfate) or INTEC (e.g., chloride) could be factors. Upgradient influences are unlikely because tritium (common to both RTC and RWMC facilities) was not detected in the affected RWMC wells. Evidence suggests that the SDA is the source of elevated bromide, chloride, magnesium, sodium, and sulfate in the Snake River Plain Aquifer south to southeast of RWMC; however, brine may not be entirely responsible for these contaminants because high chloride, sodium, and sulfate have been measured in nearby Wells USGS-88 and USGS-89 since 1977, long before brine was applied to roads in the SDA. Conversely, other USGS wells in this area



with a 17-year sampling history (i.e., Wells USGS-117 and USGS-119) do not show elevated concentrations of these anions or cations. Aquifer-sample chemistry in this area of RWMC should be somewhat comparable because screened intervals of each well have a range in common. Though most well samples in this area are collected at similar depths, the anion and cation chemistries, including their ratios, are very different. The location of aquifer monitoring wells with elevated concentrations of anions and metal, especially chromium, is all on the south-southeast side of RWMC. This may support the hypothesis that a low-permeability zone lies along the southern side of RWMC.

Both filtered and unfiltered samples are collected, and analysis results show some cations exist primarily as suspended solids (i.e., aluminum, iron, lead, and zinc), and other cations are dissolved (i.e., arsenic, chromium, magnesium, nickel, and vanadium). Most suspended solids found in the unfiltered samples probably are from natural sediment in the aquifer or corrosion of well construction material, whereas the dissolved fraction in filtered samples could be contaminants leached from buried waste, chemical constituents of magnesium chloride brine, or minerals dissolved from basalt. Most RWMC aquifer monitoring well samples contain chromium in the dissolved phase and iron and aluminum as suspended solids. This is expected because chromium is soluble, while iron and aluminum are not in local conditions (e.g., neutral-to-alkaline pH of the Snake River Plain Aquifer and the oxidizing environment).

Analyte concentrations in Well M4D are unlike all other RWMC aquifer monitoring wells. Potassium, sodium, and gross beta concentrations are about six times higher, arsenic is approximately two times higher, calcium and magnesium are approximately five times lower, and naturally occurring uranium concentrations are approximately two times lower than other RWMC wells. Sodium has a slightly increasing concentration trend, whereas other analytes show a relatively flat or slightly decreasing trend. Well M4D is much deeper than other RWMC aquifer monitoring wells (i.e., 255 versus about 198 m [838 versus about 650 ft]), and the difference in chemistry between this well and the other RWMC wells suggests that groundwater at deep levels is isolated from the shallower groundwater.

Because of the large number of reportable inorganic analysis results, a table listing each result for each aquifer well for each quarter is not included.

Table 4-85. Anion and cation concentrations greater than aquifer background levels.

Analyte	Sample Quarter (results greater than background)	Sample Concentration Range (µg/L)	Aquifer Background <sup>a</sup> (µg/L)	Well with Highest Concentration in Fiscal Year 2004	Wells with Most Detections above Background Since 1997
Aluminum	1, 2, 3	48.5 to 5,790	40 <sup>b</sup>	M17S	M17S, M15, M6S, A11A31
Arsenic	2, 3	5.3 to 11.7	5.0	M3S	M4D
Bromide	1, 2, 3	169 to 751 <sup>c</sup>	150	A11A31	A11A31
Calcium	3	46,600 to 62,000	46,000 <sup>d</sup>	M16S	M14S
Chloride	1, 2, 3	21,100 to 41,000 <sup>e</sup>	21,000 <sup>d</sup>	M15S	M15S, M6S, A11A31, M11S
Chromium	1, 2, 3	22.3 to 99.6	22 <sup>b</sup>	M3S	M1S, M6S, M15S
Fluoride	1, 2, 3	710 to 840	500	M4D	M4D
Iron	1, 2, 3	93.2 to 2,700	85 <sup>b</sup>	M16S	M17S, M6S, M15S, USGS-127, OW2
Lead	2	5.4 to 66 <sup>d</sup>	5	A11A31	A11A31
Magnesium	1, 2, 3	19,200 to 26,000 <sup>e</sup>	19,000 <sup>d</sup>	M16S	M6S
Manganese	2	17.2 to 620	15 <sup>b</sup>	M16S	M17S, M15S, M6S
Nickel	1, 2, 3	10.7 to 91.0	10 <sup>b</sup>	M16S	M11S, M6S
Nitrate-N	2	2,010 to 3,140 (160K) <sup>e</sup>	2,000	M6S	M6S
Potassium	1, 2, 3	6,100 to 27,900	6,000 <sup>b</sup>	M4D	M4D, A11A31
Selenium	1, 2, 3	4.1 to 9.5 <sup>c</sup>	4 <sup>b</sup>	M6S	M6S, OW2
Sodium	1, 2, 3	18,300 to 56,900	18,000 <sup>d</sup>	A11A31	M4D, A11A31, OW2
Sulfate	1, 2, 3	35,200 to 74,700 <sup>e</sup>	31,000 <sup>d</sup>	M6S	M15S, OW2, M6S, A11A31
Vanadium	1, 2, 3	14.1 to 17.2	14.0 <sup>b</sup>	M13S	M13S, M1S
Zinc	1, 2, 3	217 to 4,700	210 <sup>b</sup>	A11A31	A11A31

a. From Knobel, Orr, and Cecil (1992) unless noted otherwise.

b. From Knobel et al. (1999).

c. Based on aquifer well data from the 1999 plutonium background study (Roback 2003a, 2003b), the 2003 upgradient study (Roddy and Koeppen 2004), and U.S. Geological Survey data (Knobel et al. 1999). Upper concentration ranges are based on the mean concentration plus the standard deviation of the mean of these combined data sets.

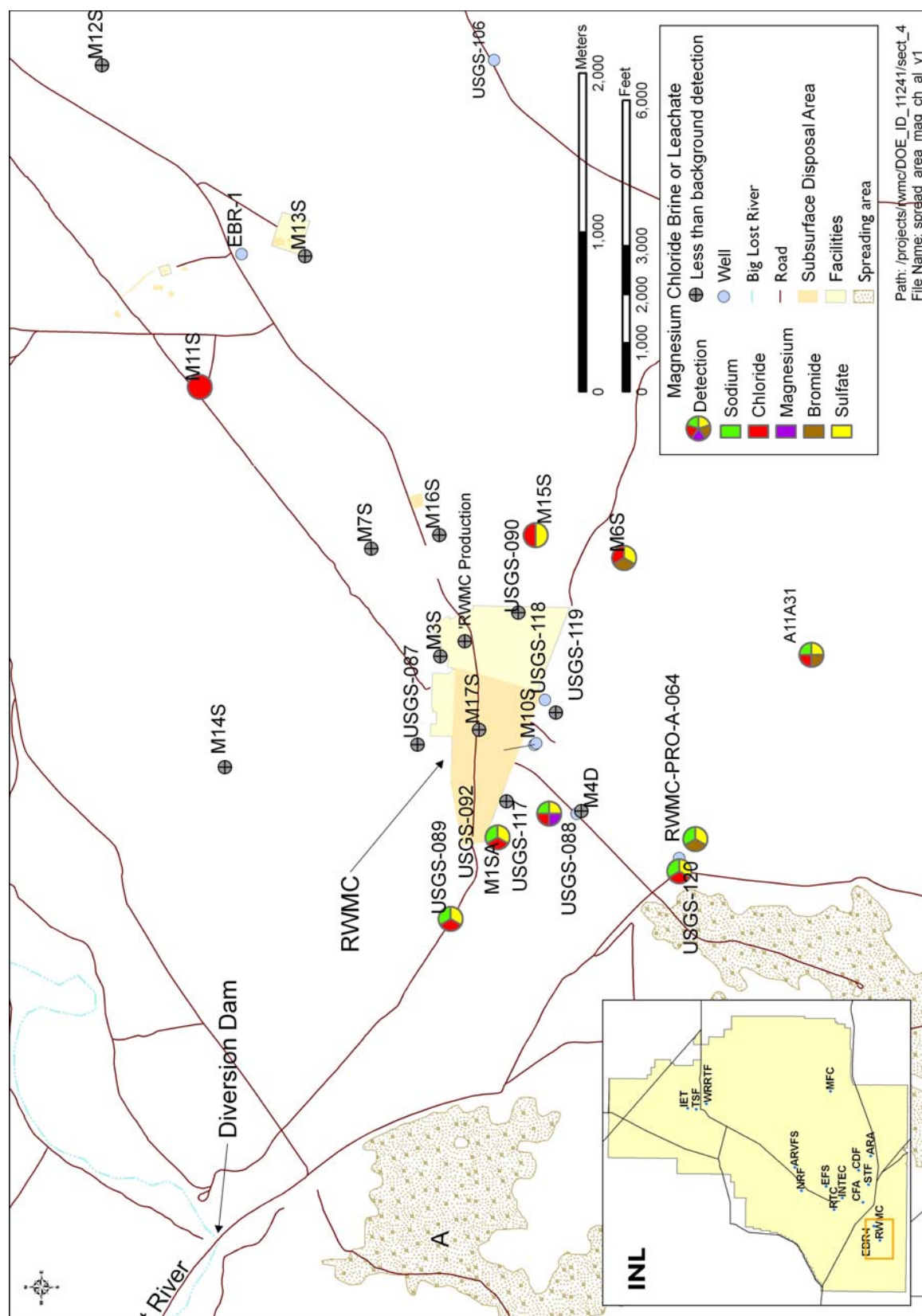
d. J-flagged data. See Koeppen et al. (2004).

e. Nitrate sample result is an outlier that may have been mistakenly preserved with nitric acid.

#### **4.21.4 Summary of Other Inorganic Chemicals**

Various chemicals are detected in the vadose zone. Most are detected only sporadically and have no associated temporal or spatial trends; however, some inorganic constituents are consistently detected, exhibit concentration trends, and show evidence of migration. These chemicals, which are not contaminants of potential concern, are primarily related to magnesium chloride brine and are useful as tracers to track water movement and infiltration paths in the vadose zone.

Very few inorganic constituents are found at concentrations greater than background levels in the aquifer beneath RWMC. None are contaminants of potential concern. Aluminum, bromide, chloride, iron, magnesium, sodium, and sulfate are the most widespread and frequently detected chemicals in the aquifer near RWMC (see Figure 4-79). None of these chemicals have associated concentration trends. Other inorganic constituents are detected that are not widespread but are distinctive to some monitoring locations (e.g., arsenic and fluoride are primarily detected in Well M4D, and lead and zinc are mostly associated with Well A11A31). Many of the anions and metals appear to be characteristic of magnesium chloride brine but could also be leachates from buried waste or could possibly be groundwater constituents from RTC (e.g., sulfate) or INTEC (e.g., chloride). A groundwater study being conducted by Waste Area Group may help determine the origin or source of these anions and metals, provide an explanation for trending concentrations, and explain the reason for the distinctive spatial patterns of some analytes and radionuclides in the aquifer around RWMC (e.g., tritium, chloride, and sulfate).



## 4.22 Carbon Tetrachloride (Volatile Organic Compound)

Carbon tetrachloride is a man-made chlorinated aliphatic hydrocarbon. Historically, carbon tetrachloride was commonly used in industry as a solvent, though less toxic substitutes are now used when technically acceptable. Multiple phases are possible, including (1) a nonaqueous-phase liquid, (2) a vapor phase in soil gas, (3) an aqueous phase dissolved in water, and (4) a solid phase sorbed onto soil particles. In the environment, carbon tetrachloride will partition into all the phases, seeking an equilibrium condition. At the SDA, however, nearly all carbon tetrachloride came from Series 743 sludge generated by weapon production processes at the Rocky Flats Plant. Significant quantities of nonaqueous-phase liquid are unlikely because of the high viscosity of treated Series 743 waste. Soil also is an insignificant medium at the SDA because carbon tetrachloride is a VOC that tends to vaporize. The nature and extent of carbon tetrachloride in soil gas and water is the focus of discussions that follow. This section presents sampling results for carbon tetrachloride in soil gas, soil moisture, and the aquifer. Sampling data in this section are evaluated against two data sets:

- Comparison concentrations shown in Table 4-1
- Soil-gas remediation goals shown in Table 4-86 (remediation goals were established by the Operable Unit 7-08 OCVZ Project [see Section 3.2.8]).

Table 4-86. Operable Unit 7-08 project remediation goals for carbon tetrachloride in soil gas.

Region or Zone Name	Horizontal and Vertical Boundaries <sup>a</sup>	Soil-Gas Remediation Goal (ppmv)
A1	Inside the SDA—land surface to B-C interbed	<190
A2	Inside the SDA—B-C interbed to C-D interbed	<39
A3	Inside the SDA—C-D interbed to water table	<7
B1	Outside the SDA—land surface to B-C interbed	<50
B2	Outside the SDA—B-C interbed to C-D interbed	<11
B3	Outside the SDA—C-D interbed to water table	<1.4

Note: Data taken from INL (2005).

a. The horizontal boundary between Region A and Region B is determined by the area effectively influenced by the vapor vacuum extraction with treatment system operated by Operable Unit 7-08. Currently, this is estimated to be approximately the same as the SDA boundary.

SDA = Subsurface Disposal Area

Careful attention should be paid to the different concentration units for carbon tetrachloride and other VOCs in gaseous and aqueous phases. Aqueous-phase concentrations are often given in mass of contaminant per volume of aqueous solution ( $\mu\text{g/L}$ ). For low concentrations,  $\mu\text{g/L}$  is the same as parts per billion, which is a mass:mass ratio (e.g., microgram of contaminant per kilogram of solution). Gaseous-phase concentrations, in comparison, are given as parts per million by volume, which is a volume:volume ratio.

Many investigations have been conducted to determine the extent of carbon tetrachloride contamination and other VOCs at the SDA. These investigations have detected carbon tetrachloride in soil gas, vadose zone soil water (perched water and lysimeter samples), and the aquifer beneath and surrounding RWMC. Carbon tetrachloride vapor also has been detected emanating from the soil surface by surface isolation flux chambers. Sources of carbon tetrachloride information and data include Mann and

Knobel (1987); Mann (1990); Liszewski and Mann (1992); Duncan, Sondrup, and Troutman (1993); Sondrup and Martian (1995); Greene and Tucker (1998); Rodriguez (2000); Miller and Varvel (2005); Housley (2003); Housley (2005); USGS Aquifer Quality Database; and results from routine vapor monitoring. The following subsections summarize information from these investigations.

#### 4.22.1 Waste Zone

**4.22.1.1 Inventory and Distribution.** The primary source of carbon tetrachloride at the SDA is Series 743 waste drums shipped from the Rocky Flats Plant between 1966 and 1970 (Miller and Varvel 2005). Initially, 9,689 drums of Series 743 waste were buried in multiple pits in the SDA, including Pits 4, 5, 6, 9, 10, 11, and 12. In the 1970s, all 1,015 drums buried in Pits 11 and 12 were retrieved, leaving 8,674 drums of Series 743 waste in the SDA. The estimated mass of carbon tetrachloride contained in these 8,674 drums is 7.86E+05 kg (see Table 4-7) (Miller and Varvel 2005). This is 99.5% of the total carbon tetrachloride mass buried in the SDA. Figure 4-25 displays a drum-density burial map for Series 743 waste drums. Table 4-87 displays the distribution of Series 743 drums and carbon tetrachloride mass within the SDA.

Table 4-87. Distribution of Series 743 waste drums and carbon tetrachloride mass after drum retrieval from Pits 11 and 12.

Location	Number of Drums (% of total)	Carbon Tetrachloride Mass (kg) (% of total)
Pit 4	3,799 (42.6)	3.48E+05 (44.3)
Pit 5	49 (0.6)	3.45E+03 (0.4)
Pit 6	2,524 (29.1)	2.36E+05 (30)
Pit 9	1,144 (13.2)	1.03E+05 (13.1)
Pit 10	1,258 (14.5)	9.57E+04 (12.2)
<b>Total</b>	<b>8,674 (100)</b>	<b>7.86E+05 (100)</b>

Though a considerable amount of VOCs has been released from Series 743 waste into the vadose zone, a significant portion may still remain in sludge in the pits. A study by Sondrup et al. (2004) attempted to estimate the mass of carbon tetrachloride and total VOCs remaining in the SDA pits using chlorine data from neutron-gamma logging of Type A probe holes along a transect through Series 743 waste in Pit 4. Although a defensible, quantifiable estimate was ultimately not possible, the study found sufficient basis to make a recommendation for modeling purposes. The study recommended using 50% of the initial VOC mass remaining as a best estimate and using 75% remaining as an upper bound.

**4.22.1.2 Waste Zone Soil-Gas Data from Type B Probes.** In 2001, 16 Type B vapor probes were installed in areas known to contain Series 743 waste. Nine were installed in the Organic Sludge Focus Area of Pit 4 and seven in the Depleted Uranium Focus Area of Pit 10. Figures 3-35 and 3-36 show Type B vapor probe locations. Samples have been collected quarterly and analyzed with a field screening instrument (Innova Model 1314 photoacoustic multigas analyzer) for five VOCs, including carbon tetrachloride. A few field duplicate samples from each sampling round are sent to a laboratory and analyzed using standard gas chromatography and mass spectrometry. The complete set of data through FY 2003 is contained in Myers et al. (2004).

Since installation, eight of the 16 probes have yielded a sample consistently. The other eight probes yielded a sample at least once and maybe more; but often, it was a low-volume sample. Probes that have

not yielded a sample may be clogged by soil moisture or possibly by sludge in the buried waste. In late 2004, all probes in the Organic Sludge Focus Area were removed to accommodate waste retrieval activities in Pit 4.

Table 4-88 contains the maximum carbon tetrachloride vapor probe concentrations as measured with the Innova gas analyzer for the eight probes that have yielded a sample consistently. Agreement has been consistent between the Innova and the gas chromatography and mass spectrometry results. At times, agreement has been very good (within a few percent); at other times, the disparity has been significant (20% or greater). The Innova was returned for recalibration on two occasions because of differences between the gas chromatography and mass spectrometry results and the standard gases.

Table 4-88. Maximum carbon tetrachloride vapor concentrations from Type B vapor probes.

Vapor Port	Port Depth (ft)	Date	Maximum Carbon Tetrachloride Concentration (ppmv)
743-08-VP1	20.2	2/17/2004	73,100
743-08-VP2	13.4	2/17/2004	79,600
743-18-VP4	14.6	12/13/2004	15,200
DU-08-VP2	15.8	5/26/2004	17,000
DU-10-VP2	10.0	8/20/2002	7,896
DU-10-VP3	6.2	8/15/2002	17,360
DU-14-VP2	11.7	9/27/2004	13,900
DU-14-VP3	4.9	5/26/2004	2,250

Expectedly, vapor probes in the waste zone yield higher concentrations than those measured in the vadose zone. Concentrations at location 743-08 are especially high and indicative of relatively undisturbed sludge because the values exceed the predicted equilibrium concentration of carbon tetrachloride for the Series 743 sludge mixture (46,000 ppmv) (Myers et al. 2004). During the 4 years of sampling (2001 to 2004), concentrations have remained fairly steady.

**4.22.1.3 Waste Zone Lysimeter Data.** Lysimeter samples from the waste zone are not routinely analyzed for organic contaminants because of limited sample volumes and analytical priorities. In December 2004, however, a liquid sample was collected from Lysimeter DU-14-L3 in the waste zone in the western end of Pit 10. The sample had an oily appearance and a petroleum-like odor. The sample was analyzed for organic contaminants—but after the 14-day holding time limit specified by the analytical method. The carbon tetrachloride concentration in the sample was 40.8 g/L. This is more than 50 times the solubility limit, indicating the sample contained liquid carbon tetrachloride.

#### 4.22.2 Surface

Surface soil, vegetation, and run-off water samples are not analyzed for VOCs. However, gaseous emissions from the soil surface of the SDA were collected in December 1992 and July 1993 using a surface isolation flux chamber. Measurements were made in the 12 locations indicated in Figure 4-80. Results for carbon tetrachloride, in terms of concentration within sample canisters and emission rates, are shown in Table 4-89. Emissions of carbon tetrachloride were detected in 10 of the 12 locations. The maximum emission rate for carbon tetrachloride was 56  $\mu\text{g}/\text{m}^2/\text{minute}$  in July 1993 at location FC-5 between Pits 4 and 10. Duncan, Sondrup, and Troutman (1993) and Schmidt (1993) record complete results of these studies.



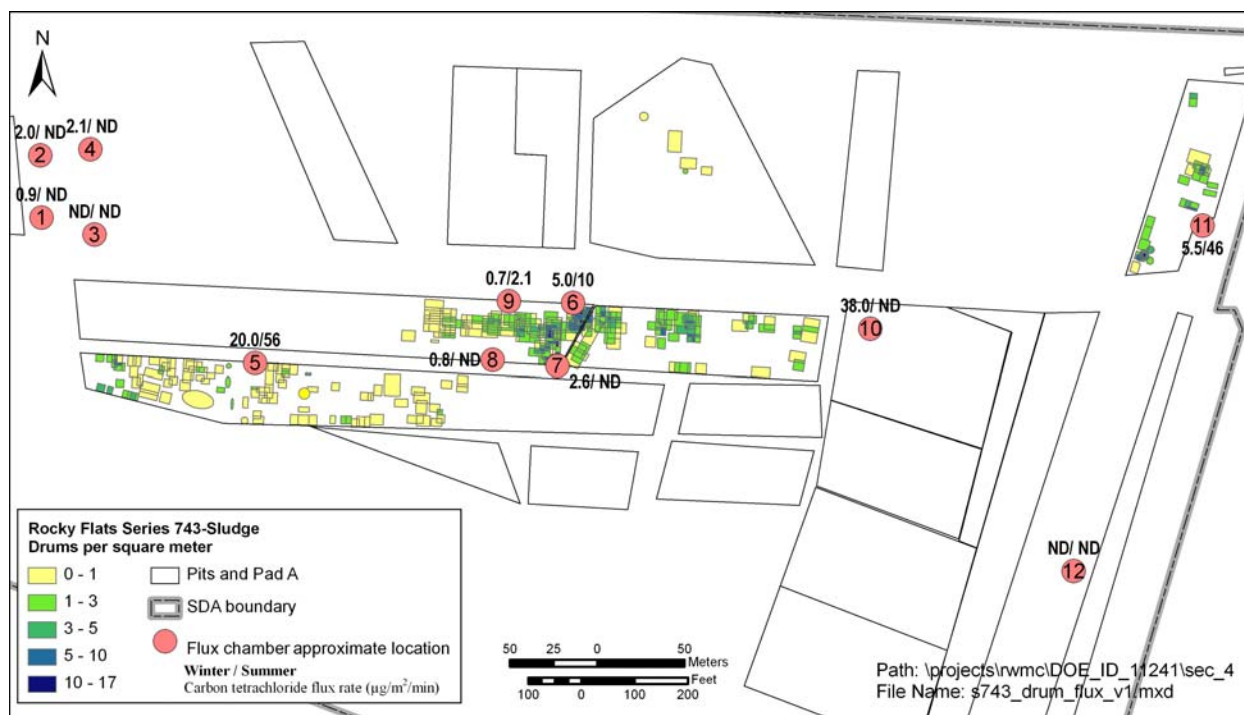


Figure 4-80. Surface isolation flux chamber measurement locations and carbon tetrachloride emission rates.

Table 4-89. Summary of carbon tetrachloride data collected from 1992 and 1993 surface flux chamber measurements.

Sample Location	December 1992		July 1993	
	Concentration in Canister (ppbv)	Emission Rate ( $\mu\text{g}/\text{m}^2/\text{minute}$ )	Concentration in Canister (ppbv)	Emission Rate ( $\mu\text{g}/\text{m}^2/\text{minute}$ )
FC-1	3.3 (3.9) <sup>a</sup>	0.87	4.5 (5.0) <sup>a</sup>	Not detected
FC-2	8.3	2.0	Not detected	Not detected
FC-3	<1	Not detected	Not detected	Not detected
FC-4	8.7	2.1	Not detected	Not detected
FC-5	85	20	240 <sup>b</sup>	56
FC-6	21	5.0	46	10
FC-7	11	2.6	Not detected	Not detected
FC-8	3.2	0.77	Not detected	Not detected
FC-9	2.9	0.70	14	2.1
FC-10	160	38	2.4	Not detected
FC-11	23	5.5	200	46
FC-12	<1	Not detected	Not detected	Not detected

a. Replicate analysis.

b. Reported value is an average of multiple results.



### 4.22.3 Vadose Zone

Carbon tetrachloride is ubiquitous in the vadose zone near RWMC, as indicated by hundreds of gas and water sample analyses. This section discusses vadose zone sample results, including (1) shallow soil-gas survey data, (2) shallow well soil-gas data, (3) deep soil-gas data, (4) perched water data, and (5) lysimeter data.

**4.22.3.1 Shallow Soil-Gas Survey Data.** Five shallow soil-gas surveys have been performed at the SDA. The first two surveys were conducted in 1987 and 1992 and covered large areas using a relatively coarse grid spacing. These surveys analyzed samples using portable gas chromatographs and produced respective carbon tetrachloride concentration ranges of 0 to 427 and 0 to 255 ppmv. Surveys conducted in 1999 and 2000 used a finer spacing and were focused in areas over Pits 4, 5, 6, and 10, identified by the previous surveys as Series 743 waste burial locations. These surveys analyzed samples using a Brüel and Kjær portable photoacoustic multigas analyzer. Carbon tetrachloride concentration ranges for the 1999 and 2000 surveys vary from 2 to 7,260 and 0 to 6,330 ppmv, respectively. Because the 1999 and 2000 surveys were focused over specific pits where Series 743 waste drums are buried, the maximum measured concentrations are much greater than the first two surveys.

Objectives of the survey performed in 2001 were to (1) obtain data to validate or refute the presence of carbon tetrachloride in the eastern end of Pit 2 detected during the 1992 survey and (2) determine, if possible, the effects of probe installation on release of VOCs in the Organic Sludge Focus Area in Pit 4. Data provided evidence that Pit 2 is not a significant source of VOCs, as data from the 1992 survey might suggest. Data from the 2001 survey were inconclusive in relating VOC releases to probe installation.

Results of the five surveys generally agree in terms of identifying burial locations of VOCs contained in Series 743 waste. Figure 4-81 shows a contour map of carbon tetrachloride concentrations from the 2000 shallow soil-gas survey. To a large degree, this information validates the Series 743 waste burial locations shown in Figure 4-25. Housley, Sondrup, and Varvel (2002) summarized all five shallow soil-gas surveys.

**4.22.3.2 Shallow Well Soil-Gas Sampling.** In August 1992, gas samples were collected from gas-sampling ports in Wells TEM1A, TEM2A, and TEM3A (see Figure 4-45 for well locations). Sampling ports are located in the surficial sediment at 0.6-m (2-ft) depth intervals down to basalt. Samples were analyzed at the INL Site with a Sentex scentograph portable gas chromatograph. Table 4-90 provides a summary of carbon tetrachloride results from these analyses. The maximum concentration measured was 103 ppmv in Well TEM-1A at a depth of 4.9 m (16 ft). The vertical profile in each well shows an increase with depth in carbon tetrachloride concentrations. For additional details, see Duncan, Sondrup, and Troutman (1993).

Later in the same year, other shallow well soil-gas samples were collected and analyzed from locations around the Acid Pit and Pit 9. Results of these samples were consistent with TEM-series well sample results and the 1992 shallow soil-gas survey.

**4.22.3.3 Deep Soil-Gas Data.** Soil-gas or soil-vapor monitoring in the vadose zone is accomplished using an extensive system of permanent soil-vapor-sampling ports located inside and outside the SDA boundary (see Figures 4-45 and 4-46). Routine and reliable soil-vapor monitoring began in 1993.

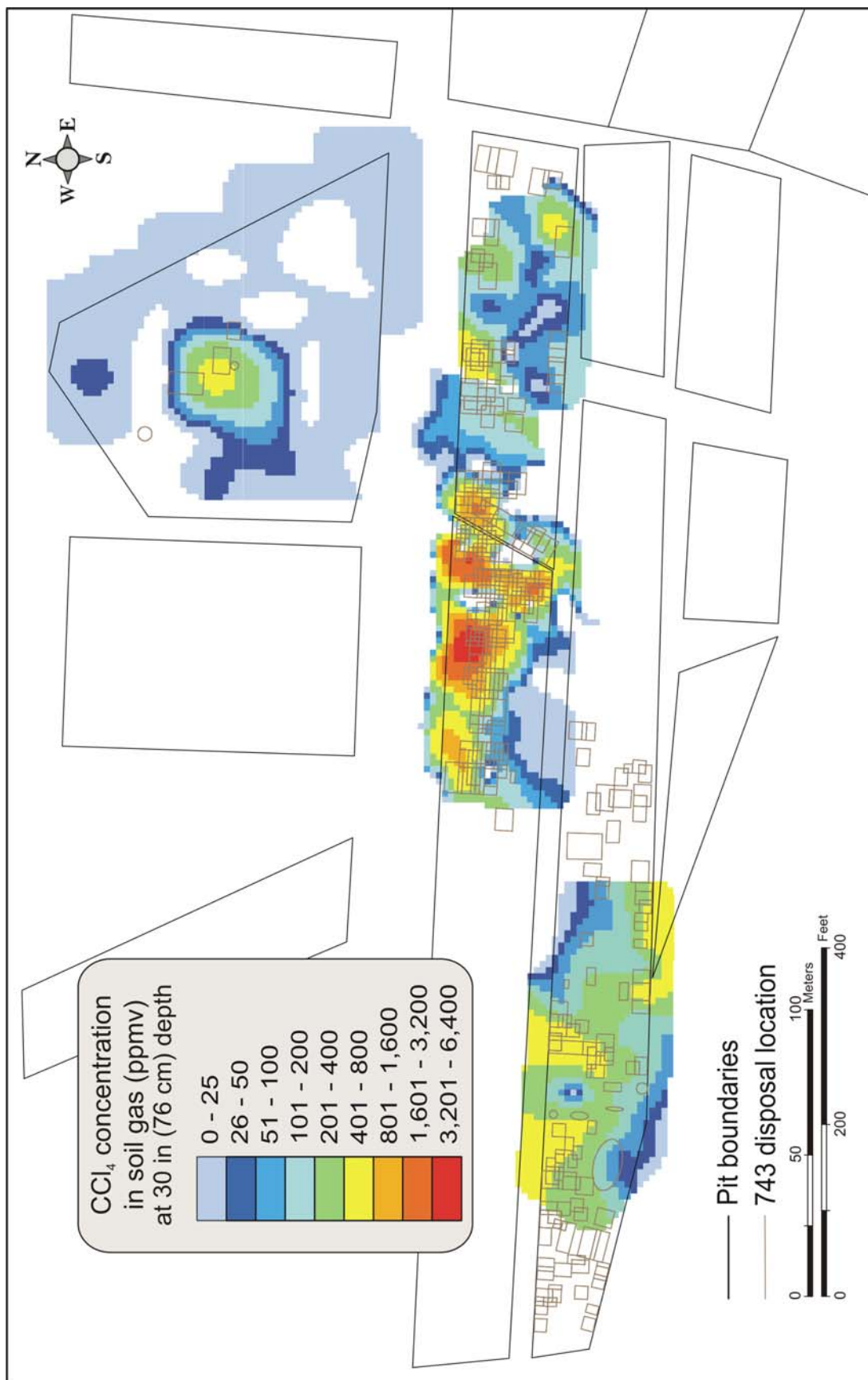


Figure 4-81. Carbon tetrachloride concentrations (ppmv) in shallow soil gas measured during the 2000 shallow soil-gas survey.

Table 4-90. Summary of carbon tetrachloride vapor concentration results from August 1992 TEM-series well samples.

Well	Mean Concentration (ppmv)								
	Depth Below Soil Surface (ft)								
	2	4	6	8	10	12	14	16	18
TEM1A	8.79	13.9	13.7	13.6	16.7	20.0	89.7	103	NP
TEM2A	ND	2.49	3.39	17.1	23.8	NP	NP	NP	NP
TEM3A	8.62	13.6	24.0	NS	NS	NS	NS	69.8	147

ND = Not detected at 0.1 ppm  
 NP = No port  
 NS = No sample

In January 1996, Operable Unit 7-08 began operating a multi-well vapor vacuum extraction with treatment system inside the SDA to remove gaseous-phase VOCs from the subsurface (see Section 3.2.8). This system has operated on a nearly continuous basis since 1996 and greatly altered deep soil-gas concentrations. Figure 4-82 shows conceptually the vadose zone soil-gas concentrations before operation of the vapor vacuum extraction with treatment system. Highest levels of carbon tetrachloride were located in the central portion of the SDA between Pits 4, 5, 6, and 10. The maximum concentration measured was 4,864 ppmv in Well 9302 Port 6 at a depth of 23.5 m (77 ft) in January 1995. Data from wells outside the SDA indicate carbon tetrachloride has migrated more than 1 km (3,281 ft) beyond the SDA boundary, but concentrations decrease significantly with distance from the SDA. Carbon tetrachloride concentrations in wells only 250 m (820 ft) from the SDA boundary are approximately two orders of magnitude less than concentrations below the buried waste. Concentrations in the wells farthest from the SDA (i.e., OCVZ-11 and OCVZ-13) are less than 1 ppmv. Though Wells OCVZ-11 and OCVZ-13 were installed after 1996, the vapor vacuum extraction with treatment system probably has not influenced concentrations so far away. Figure 4-111 contains three-dimensional figures showing average carbon tetrachloride vapor concentrations in the SDA subsurface in 2004.

Vertically, carbon tetrachloride contamination extends from land surface down to the water table. Figure 4-83 shows time-averaged vertical concentration profiles of carbon tetrachloride before vapor vacuum extraction with treatment system operations for Wells 8801, 9301, and 9302, located near the center of the SDA. The figure does not include data collected during the 1993 OCVZ treatability study. Concentrations increased with depth from near zero at land surface to several thousand ppmv above the B-C interbed. Concentrations decreased sharply across the B-C interbed down to several hundred ppmv. From just below the B-C interbed down to the C-D interbed, concentrations decreased from several hundred ppmv to a few hundred ppmv. Until recently, concentrations below the C-D interbed inside the SDA were not known. Now, six wells inside the SDA have vapor ports below the C-D interbed. Currently, carbon tetrachloride concentrations below the C-D interbed are less than 20 ppmv in nearly all ports in those wells.

Figure 4-84 shows the soil-gas concentration vertical profile for carbon tetrachloride in the V- and VVE-series wells before the start of vapor vacuum extraction with treatment system operations. As expected, concentrations decrease with distance away from the Series 743 sludge source areas. The highest concentration in the V-series wells inside the SDA is less than 600 ppmv; in the VVE-series wells outside the SDA, the highest concentration is less than 80 ppmv. In wells farthest away from the Series 743 sludge source areas (i.e., Wells 9V, 10V, VVE1, VVE3, VVE4, VVE6, and VVE7), the highest concentrations are located below the B-C interbed and below the C-D interbed in some cases.

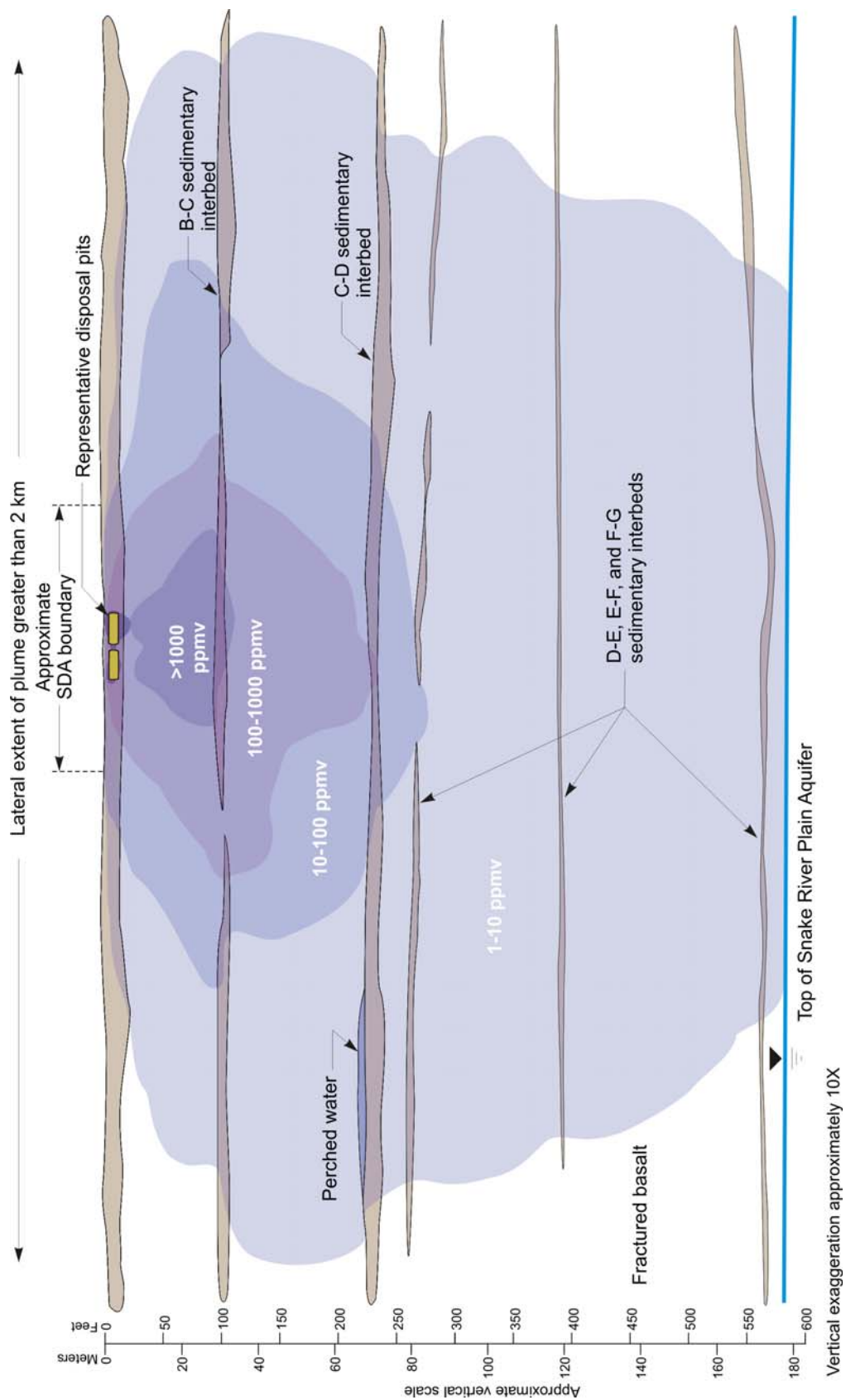


Figure 4-82. Conceptual drawing of the carbon tetrachloride soil-gas plume before vapor vacuum extraction with treatment system operations.

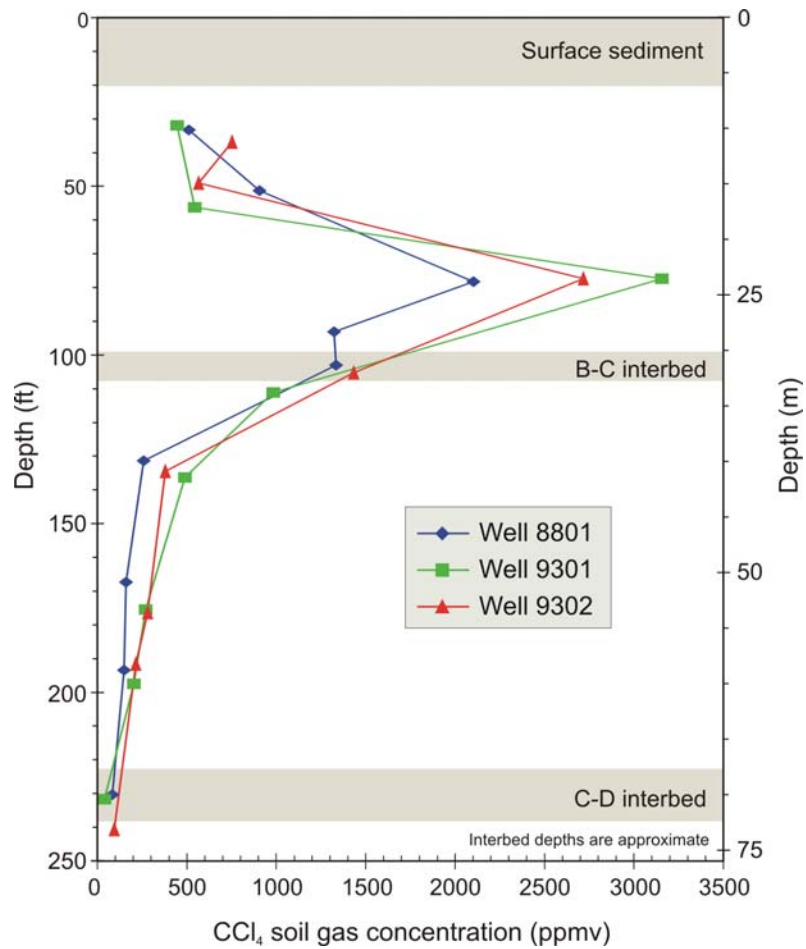


Figure 4-83. Vertical profiles of carbon tetrachloride soil-gas concentrations for Wells 8801, 9301, and 9302 near the center of the Subsurface Disposal Area, averaged from April 1993 to October 1995.

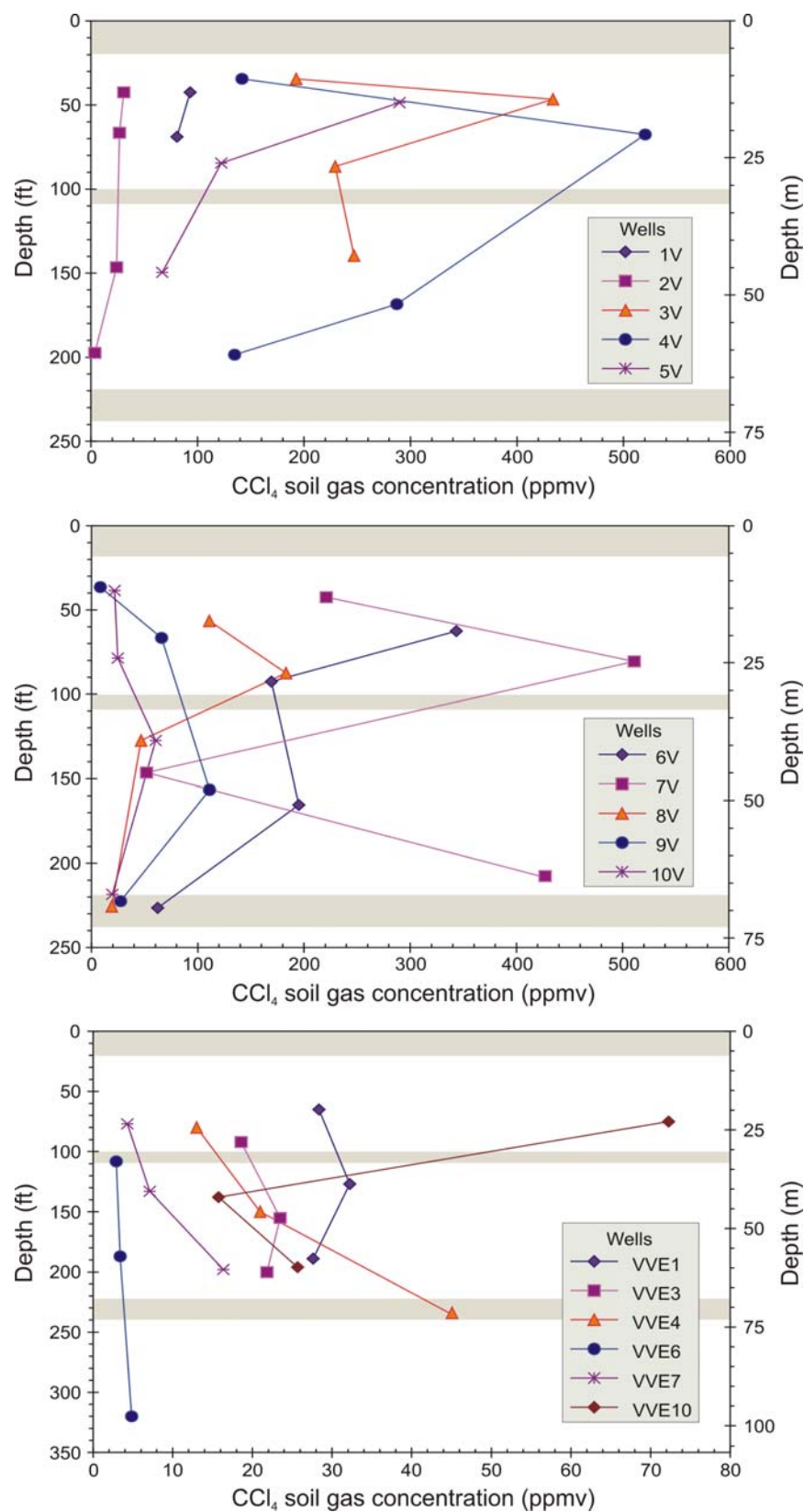


Figure 4-84. Vertical profiles of carbon tetrachloride soil-gas concentrations for V- and VVE-series wells averaged from January 1995 to October 1995.

This pattern is likely caused by lateral migration of soil gas below the B-C interbed under the source areas. Also, soil gas above the B-C interbed will dissipate more rapidly as it migrates laterally because of surface volatilization and barometric pumping.

Since the startup of vapor vacuum extraction with treatment system operations in January 1996, soil-gas concentrations have decreased markedly at many locations in response to gas extraction. Figures 4-85 and 4-86 show soil-gas concentrations at Wells 8801 and 9301 near vapor extraction Well 8901D. Before 1996, the carbon tetrachloride concentration at the 21-m (70-ft) depth (above the B-C interbed) was approximately 3,000 ppmv in these two wells. After gas extraction began, the concentration dropped to about 1,000 ppmv. In Well 9V (see Figure 4-87), the initial drop in concentration was not so dramatic, probably because the well is located farther from an extraction point; nevertheless, the decrease has been steady. Even the deep gas port at 68 m (223 ft) shows a clear decline in concentrations. Ports 8801-4 and 9301-6 show a rather large rebound (increase) in carbon tetrachloride concentration in late 2003 and early 2004. This occurred because several months were required to decommission vapor vacuum extraction with treatment system Units A and B and replace them with newer catalytic oxidizers (i.e., Units E and F). Some rebound also appears in data from Well 9V, but not as dramatic.

Results similar to those shown in Figures 4-85, 4-86, and 4-87 have been observed at many of the soil-gas monitoring well locations inside the SDA. This is evident from data provided in Figure 4-88, which compares the results of carbon tetrachloride soil-gas concentrations at the 21-m (70-ft) depth in January 1996 (i.e., just before the commencement of vapor vacuum extraction with treatment system operations) with those measured in May 2005 (i.e., after more than 9 years of operation). Figure 4-88 shows concentrations in 2005 to be significantly less than in 1996; however, results may be misleading because 2005 data do not reflect an equilibrium condition. In a classic soil-gas removal system, subsurface concentrations are reduced and held to low levels when the system is operating. After the system is shut down, subsurface concentrations rebound (i.e., increase) to an equilibrium condition dependent on several geologic and contaminant-specific factors. The time required for organic contaminants in the vadose zone to achieve full rebound has not been determined. The longest the entire system has been shut down was a 9-week period during the summer of 2000. Data indicate that concentrations were still increasing at some locations. Though individual VOC treatment units have been shut down for longer than 9 weeks, all vapor vacuum extraction with treatment system units in the system must be shut down to determine rebound.

One other potentially misleading aspect of Figure 4-88 is low concentrations shown in the area around Pit 9. While this may be the case, data in the vicinity of Pit 9 are lacking. Because Pit 9 contains approximately 15% of the VOC inventory, higher soil-gas concentrations are expected, but no specific data are available to either support or refute this hypothesis.



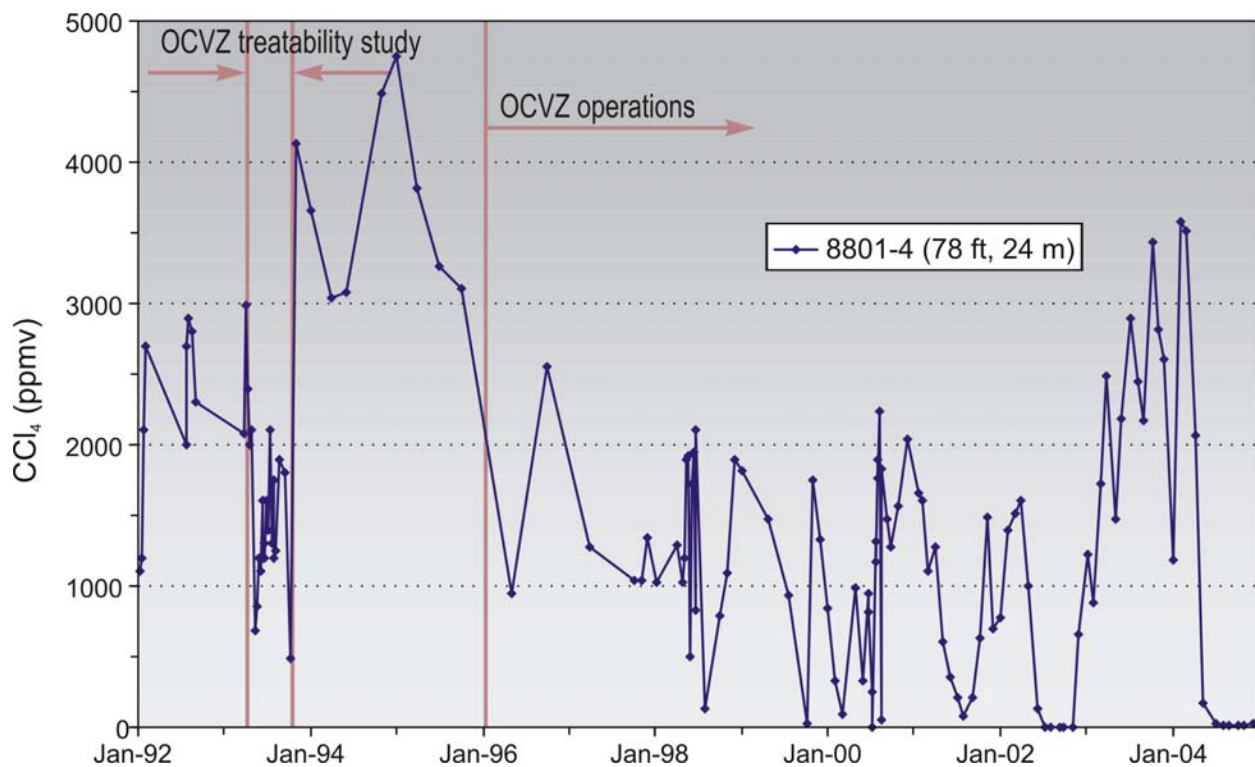


Figure 4-85. Carbon tetrachloride soil-gas concentration at the 78-ft depth timeline for Well 8801, Port 4.

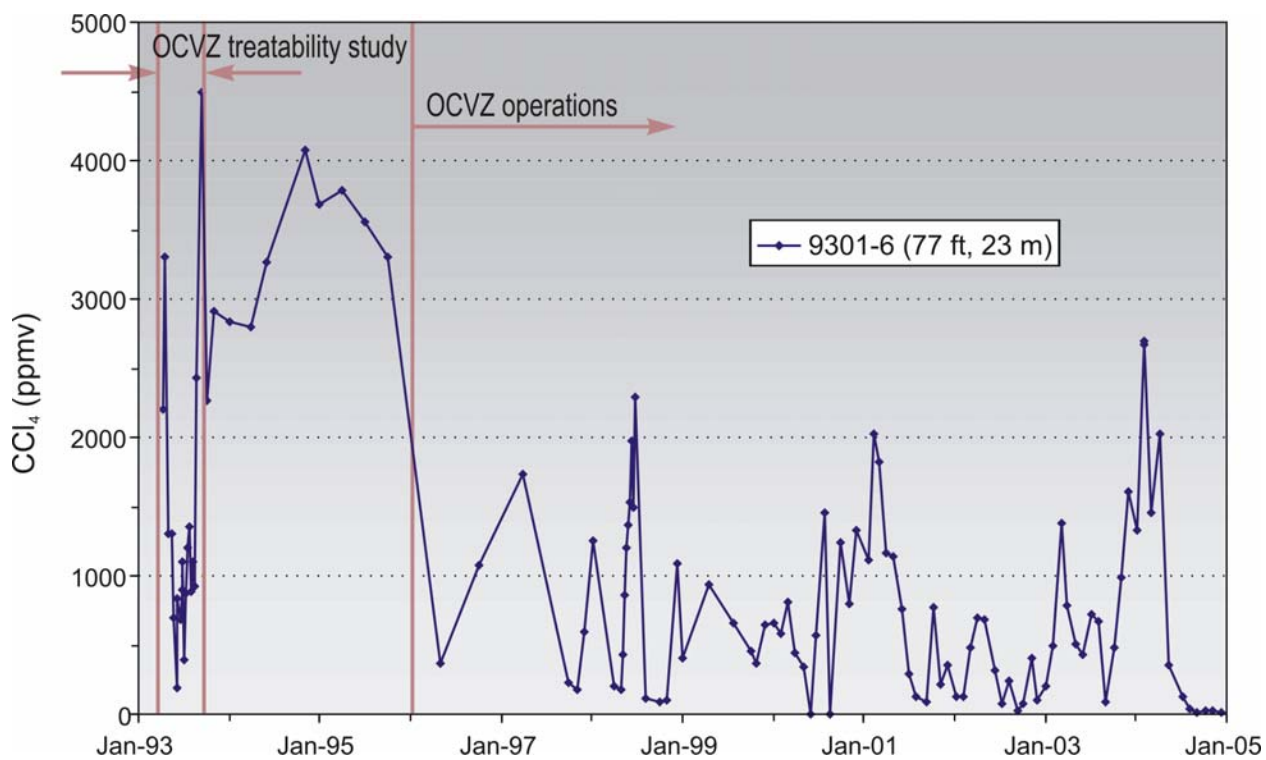


Figure 4-86. Carbon tetrachloride soil-gas concentration at the 77-ft depth time history for Well 9301.



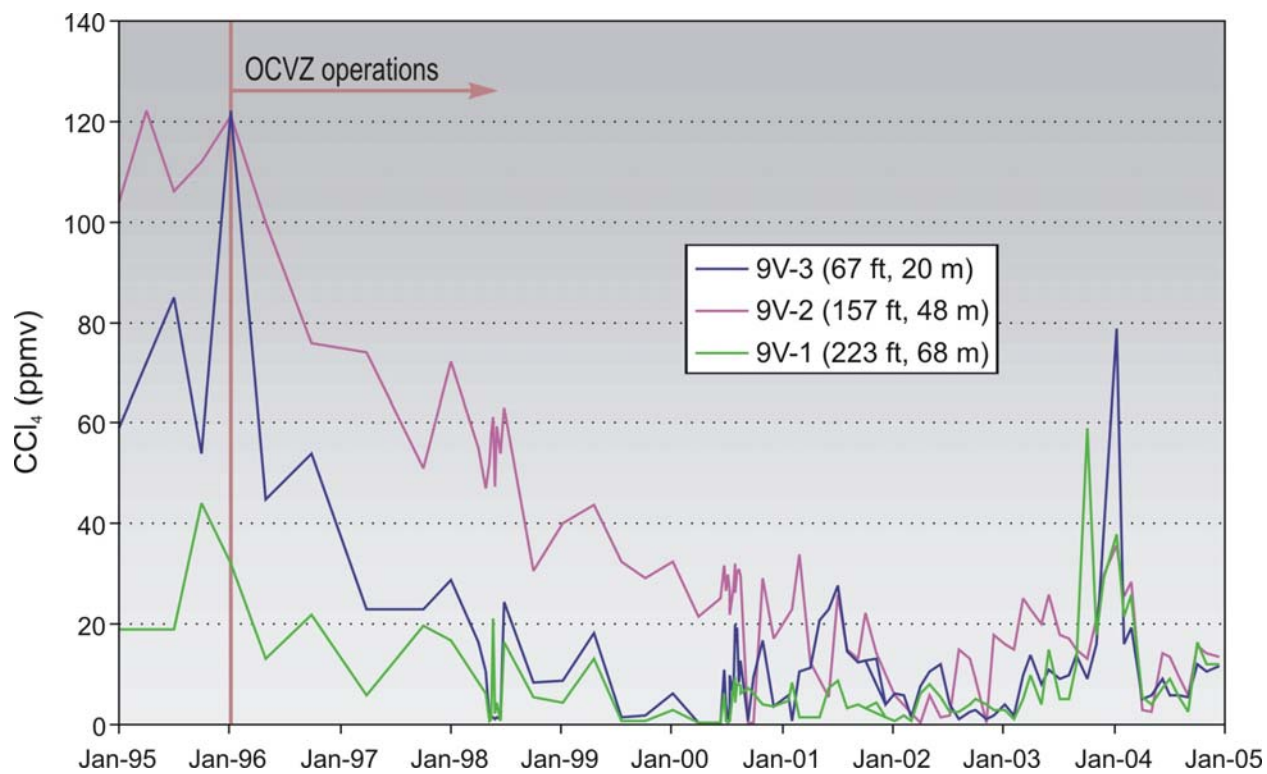


Figure 4-87. Carbon tetrachloride soil-gas concentration time history for selected ports in Well 9V.

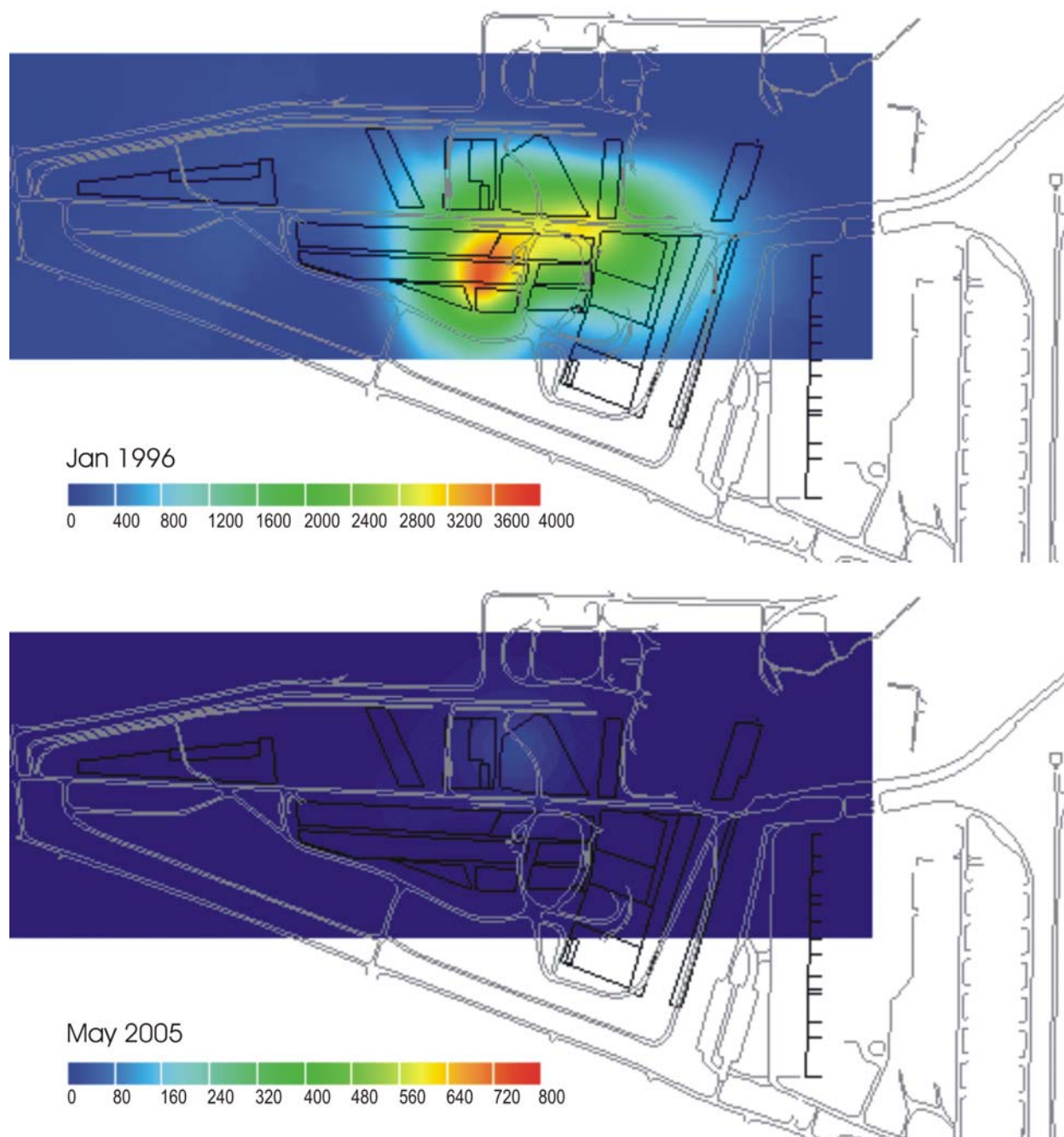


Figure 4-88. Carbon tetrachloride concentrations at the 70-ft depth just before commencement of vapor vacuum extraction with treatment system operations in January 1996 and in May 2005, after 9 years of operation.

**4.22.3.4 Perched Water Data.** Carbon tetrachloride and other VOCs have been detected in perched water samples from Wells USGS-92, 8802D, and D10 located inside the SDA. Only a limited set of perched water data exists for the SDA because of the infrequent development of perched water. Table 4-91 shows the sample depths and carbon tetrachloride concentrations. The highest concentration (2,400 µg/L) was detected in Well USGS-92 in 1992. Before full-scale operation of the vapor vacuum extraction with treatment system began in 1996, carbon tetrachloride concentrations in perched water from Well USGS-92 ranged from 1,200 to 2,400 µg/L. Since that time, concentrations have been less than 400 µg/L. Concentrations in perched water from Well USGS-92 respond directly to operation of the vapor vacuum extraction system because Well 7V (a vapor extraction well) is located near Well USGS-92. As soil gas containing carbon tetrachloride vapor is removed by vapor extraction, carbon tetrachloride in the perched water partitions into the surrounding soil gas to maintain an equilibrium ratio. The timeline of carbon tetrachloride concentration in perched water in Well USGS-92 is shown in Figure 4-89. The last perched water sample to be analyzed for VOCs was collected from Well USGS-92 in April 2003.

Table 4-91. Carbon tetrachloride data for perched water samples in Wells USGS-92, 8802D, and D10 at the Subsurface Disposal Area.

Perched Water Well	Depth <sup>a</sup> (ft)	Date	Concentration (µg/L)
USGS-92	214	October 1987	1,200
		April 1988	1,400
		April 1992	2,400
		August 1992	2,100
		February 1996	1,800
		April 1997	990
		April 1997	<20 <sup>b</sup>
		August 1997	<100 <sup>b</sup>
		February 1998	31
		March 1998	260
		March 1999	14
		April 2000	291
		April 2001	377
		April 2002	150
		April 2003	279
8802D	220	July 1989	110
		August 1992	190
		February 1998	38
D10	238	August 1992	20

a. Depths of open or screened intervals are as follows:

- USGS-92: 19 to 214 ft
- 8802D: 211 to 221 ft
- D10: 220 to 238 ft.

b. Concentrations are reported to be less than this value due to a large dilution factor.

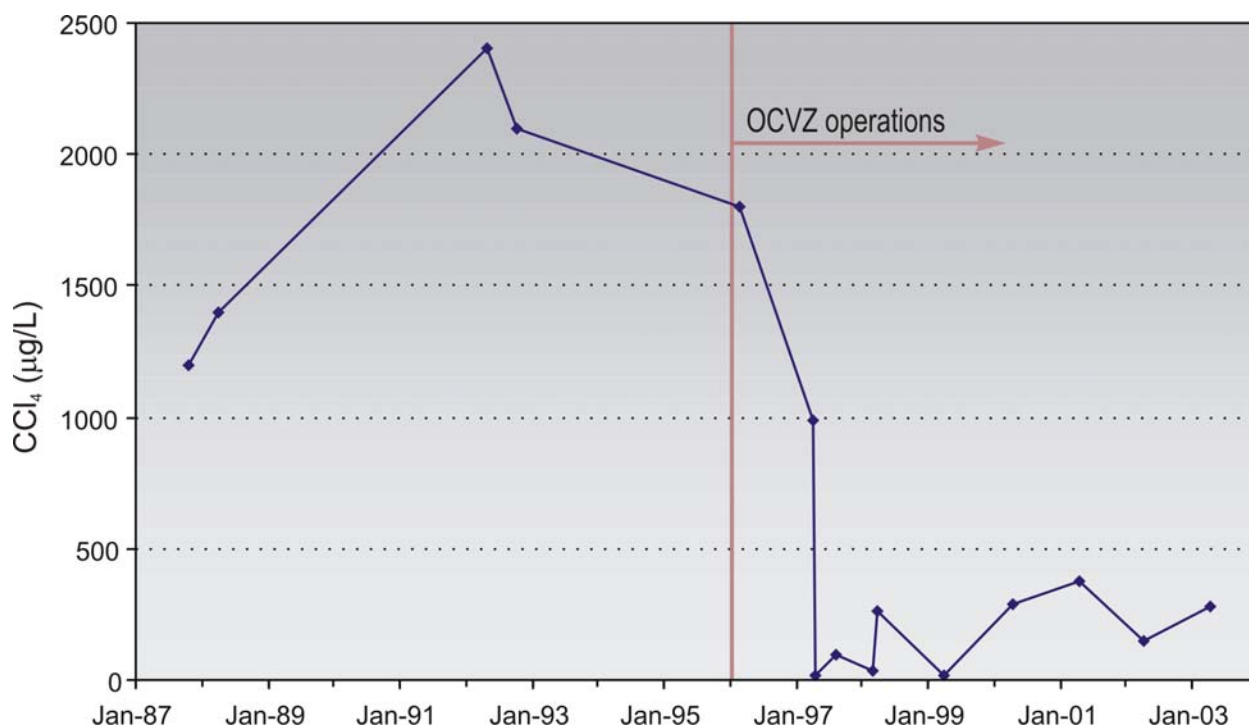


Figure 4-89. Carbon tetrachloride concentrations in perched water in Well USGS-92.

**4.22.3.5 Lysimeter Data.** Carbon tetrachloride was detected in 37 of 43 lysimeter samples collected between 1997 and 2000, representing 12 of the 13 lysimeters that produced the samples. Lysimeter samples have not been analyzed for organic contaminants since September 2000 because of limited sample volumes and analytical priorities. Nine of the lysimeters with carbon tetrachloride detections are shallow lysimeters; one was an intermediate-depth lysimeter (i.e., DO6-DL2), and one was a deep lysimeter (i.e., I3D-DL12). Lysimeter locations and depth intervals are shown in Figures 4-41, 4-42, and 4-43. Table 4-92 shows the maximum concentrations detected in each of the lysimeters, excluding estimated values (J-flagged data [i.e., positively identified, but concentration estimated]). Thirty of the 37 detections were greater than the MCL of 5 µg/L used for comparison.

#### 4.22.4 Aquifer

The first VOC analyses for the aquifer beneath the INL Site were performed in 1987 as part of a reconnaissance survey by USGS. Since that time, low levels of carbon tetrachloride have been consistently detected in aquifer wells in the vicinity of RWMC that are or have been monitored for VOCs.

Twenty-two aquifer monitoring wells within 3.2 km (2 mi) of the RWMC boundary have been monitored for VOCs. Two of those wells (i.e., M10S and USGS-90) are not currently monitored. Carbon tetrachloride has been consistently detected in 15 of the 22 RWMC-vicinity wells, with concentrations ranging from nondetect (less than 0.2 µg/L) to a maximum concentration of 8 µg/L in Well M7S during consecutive quarters in 1999 and again in 2003. Concentrations in seven of the 22 wells have exceeded the MCL of 5 µg/L at least once. Concentrations in two wells (i.e., M7S and RWMC Production Well) currently exceed the MCL. Table 4-93 contains a summary of the carbon tetrachloride groundwater results. Maximum carbon tetrachloride concentrations in groundwater are shown in Figure 4-90.

Table 4-92. Maximum carbon tetrachloride concentrations in lysimeters.

Lysimeter	Depth (ft)	Date	Concentration (µg/L)
PA01-L15	14.3	August 1998	190
PA02-L16	8.7	December 1998	980
98-5L39	10.5	August 1998	1.9
W05-L26	6.7	November 1998	19
W06-L27	11.8	April 1997	14
W08-L13	11.3	April 1997	130
W08-L14	6.2	April 1997	73
W23-L08	11.8	August 1998	37
W23-L09	7.7	August 1998	20
W25-L28	15.5	April 1997	61
D06-DL02	44	April 1997	1,000
I3D-DL12	233	December 1999	460

Table 4-93. Summary of carbon tetrachloride data from aquifer monitoring wells near the Subsurface Disposal Area.

Number of Wells	Monitoring Status	Well Names
22	Wells monitored for carbon tetrachloride in the vicinity of the Subsurface Disposal Area	M1S, M3S, M4D, M6S, M7S, M10S, <sup>a</sup> M11S, M13S, M14S, M15S, M16S, M17S, OW-2, A11A31, RWMC Production Well, USGS-87, USGS-88, USGS-89, USGS-90, <sup>a</sup> USGS-117, USGS-119, and USGS-120
15	Wells with positive detections for carbon tetrachloride	M3S, M6S, M7S, M10S, <sup>a</sup> M14S, M15S, M16S, M17S, OW-2, A11A31, RWMC Production Well, USGS-87, USGS-88, USGS-90, <sup>a</sup> and USGS-120
7	Wells with nondetections for carbon tetrachloride	M1S, M4D, M11S, <sup>b</sup> M13S, <sup>b</sup> USGS-89, USGS-117, and USGS-119 <sup>b</sup>
7	Wells with carbon tetrachloride concentrations historically exceeding the MCL	M7S, M10S, M16S, A11A31, RWMC Production Well, USGS-88, and USGS-120
2	Wells with carbon tetrachloride concentrations currently exceeding the MCL	M7S and RWMC Production Well

a. Well is not currently monitored.

b. Two or fewer results per well greater than the minimum detection limit (J-flagged data).

MCL = maximum contaminant level

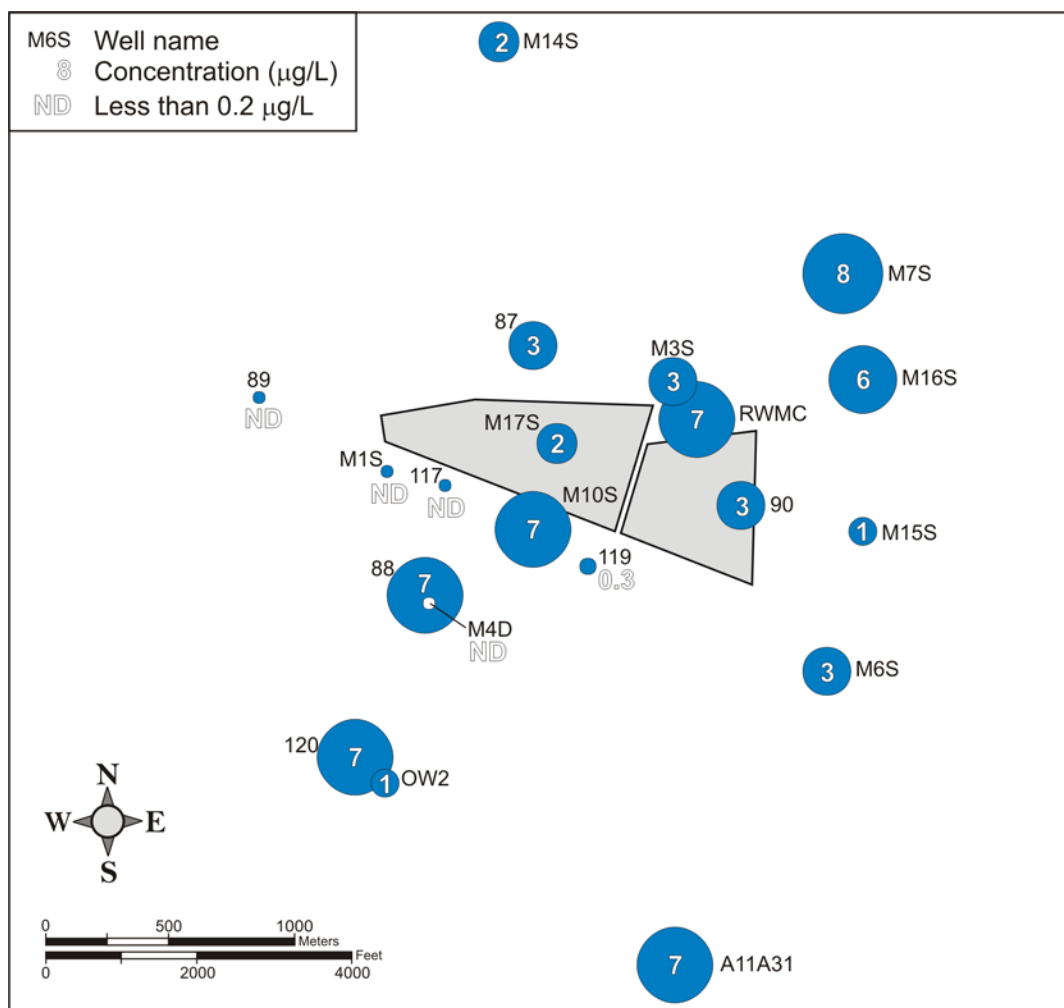


Figure 4-90. Maximum carbon tetrachloride concentrations ( $\mu\text{g/L}$ ) in the Snake River Plain Aquifer, in the vicinity of the Subsurface Disposal Area.

Figure 4-91 shows the transient behavior of carbon tetrachloride in 20 of the 22 RWMC-vicinity aquifer wells. All wells where carbon tetrachloride has been detected are shown on the map, with the exception of Wells M11S and M13S. The concentration of only one sample from each of those two wells has been greater than the detection limit, and both were estimated concentrations assigned a data qualifier (J-flag).

One of the most noteworthy and surprising features of the carbon tetrachloride distribution is the contrast in concentrations between wells close to the SDA and wells farther from the SDA. All five wells shown in Figure 4-91 that currently yield nondetections for carbon tetrachloride (i.e., Wells USGS-89, M1S, USGS-117, M4D, and USGS-119) are very close or relatively close to the SDA boundary. Furthermore, concentrations in Well M17S also are relatively low despite being the only well inside the SDA and immediately below the highest concentration of Series 743 sludge. Conversely, some of the wells with the highest concentrations (e.g., Wells M7S, M16S, USGS-120, and A11A31) are located at considerably greater distances from the SDA. Low concentrations in many wells close to the SDA are probably a result of the wells being located in a low-permeability zone. Otherwise, concentrations in wells near the SDA should be higher, based on proximity to the source and vadose zone soil-gas monitoring.



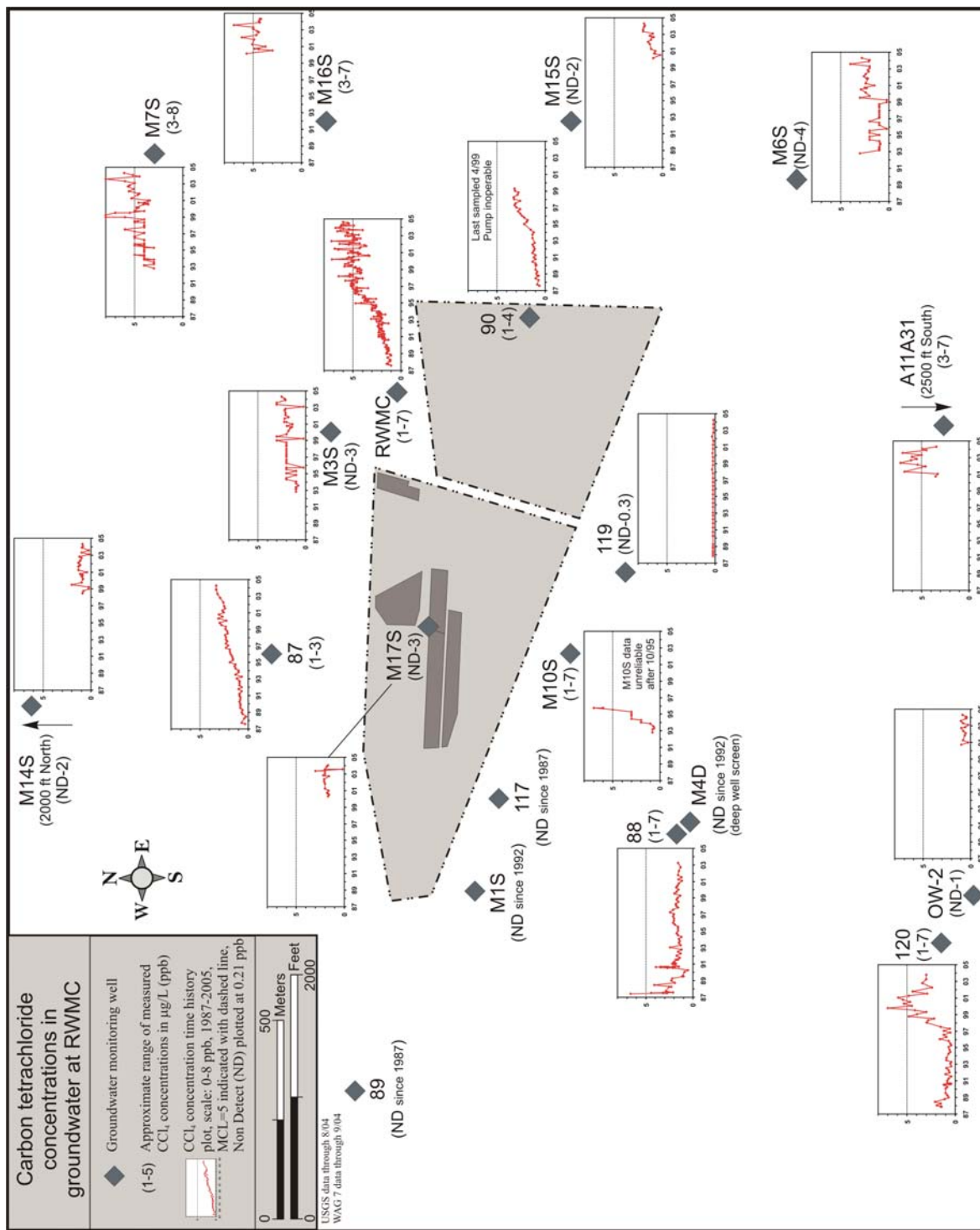


Figure 4-91. Carbon tetrachloride aquifer concentrations in monitoring wells in the vicinity of the Subsurface Disposal Area.

For most wells, the long-term concentration trend is either increasing or constant. Concentrations steadily increased for many years in Wells USGS-87, USGS-90, M3S, M7S, and RWMC Production Well. However, the past few years show a relatively flat trend in concentration in these wells, which are to the northeast of the SDA. Other wells exhibiting flat concentration trends are Wells USGS-88, M6S, and M14S. Concentrations in the other wells (i.e., M15S, M16S, M17S, OW-2, and A11A31) appear to be steady, but the period of data collection is short compared to other wells.

In terms of historic increases, the rise in concentration in Wells M10S and USGS-120 is the most remarkable. Concentrations in Well M10S increased from less than 1 µg/L to 7 µg/L in a period of 2 years from 1993 to 1995. Concentrations measured for several years after 1995 in Well M10S were below the detection limit, but data are not reliable because steel tapes were dropped in the well in late 1995 and 1998. Iron from the disintegrating tapes may have acted as a catalyst in degrading carbon tetrachloride, thus diminishing the concentrations. Concentrations in Well USGS-120 (approximately 1.7 km [0.75 mi] downgradient from Well M10S) exhibited a similar increase from 1997 to 1999. From 1999 to 2003, however, concentrations dropped to around 3 µg/L and have remained steady since that time.

#### **4.22.5 Summary of Carbon Tetrachloride**

Carbon tetrachloride is ubiquitous in the subsurface in and around the SDA. In the vadose zone, carbon tetrachloride contamination extends vertically from land surface down to the water table and laterally more than 1 km (0.62 mi) beyond the SDA boundary. Carbon tetrachloride vapor has been consistently measured in the surficial sediment, the waste zone, and at more than 100 permanent soil-gas monitoring locations in the vadose zone. Carbon tetrachloride also has been measured in perched water and lysimeter samples. A single waste zone lysimeter sample also contained liquid carbon tetrachloride. Vadose zone soil-gas concentrations generally range from a few ppmv on the outskirts of the plume to a few thousand ppmv above the B-C interbed near the center of the SDA. The vapor vacuum extraction with treatment system, operated by Operable Unit 7-08, has reduced the vadose zone contamination significantly since it began operation in 1996.

Low levels of carbon tetrachloride have been measured in the aquifer since 1987. Carbon tetrachloride has been consistently detected in 15 of the 22 RWMC-vicinity wells, with concentrations ranging from nondetect (less than 0.2 µg/L) to a maximum concentration of 8 µg/L measured in Well M7S. Concentrations in seven of the 22 wells have exceeded the MCL of 5 µg/L at least once, and concentrations in two wells (i.e., M7S and RWMC Production Well) currently exceed the MCL. The long-term trend in aquifer concentrations is increasing, but over the past several years, concentrations appear to have stabilized in many of the wells; however, conclusions about the effectiveness of the vapor vacuum extraction with treatment system on aquifer concentrations cannot be determined. Table 4-94 shows detection frequencies for carbon tetrachloride in aqueous samples from the vadose zone and aquifer.



Table 4-94. Carbon tetrachloride detection frequencies for aqueous samples.

Media	Number of Detections	Detection Rate (%)	Range of Detected Concentrations (µg/L) <sup>a</sup>	Total Number of Detections Greater Than Maximum Contaminant Level <sup>a,b</sup>	Wells with Detections Greater Than Maximum Contaminant Level
<b>Vadose zone</b>					
Soil moisture (0 to 35 ft)	33	85	1.9 to 980	30	PA01-L15, PA02-L16, W05-L26, W06-L27, W08-L13, W08-L14, W23-L08, W23-L09, W25-L28
Soil moisture (35 to 140 ft)	2	100	110 to 1,000	2	D06-DL02
Soil moisture (>140 ft)	2	100	240 to 460	2	I3D-DL12
				17	
Perched water	17	100	14 to 2,400	17	USGS-92, 8802, D10
<b>Aquifer</b>					
Idaho National Laboratory Site and U.S. Geological Survey wells (since 1987)	815	74	0.21 to 8	106	M7S, M10S, M16S, A11A31, RWMC Production Well, USGS-88, USGS-120
<p>a. Estimated data assigned a J-flag qualifier were excluded when determining the range of detected concentrations; however, they were included when determining the number of detections greater than the MCL.</p> <p>b. MCL is 5 µg/L used for comparison.</p> <p>MCL = maximum contaminant level</p>					

## 4.23 1,4-Dioxane (Volatile Organic Compound)

1,4-dioxane is a stabilizer compound added to solvents to enhance life and prevent decomposition from such influences as light, heat, oxygen, acids, and metal salts. 1,4-dioxane also is used as a solvent in lacquers, paints, oils, and plastics. At Rocky Flats Plant, 1,4-dioxane was a component in 1,1,1-trichloroethane-based solvents and is therefore a component of Series 743 sludge. Other common names for 1,4-dioxane include p-dioxane, methyl chloroform, diethylene ether, and diethylene dioxide.

Although 1,4-dioxane is listed as a VOC in many references, its moderate vapor pressure and complete miscibility in water make it unlikely to form a vapor plume. Significant quantities of a nonaqueous-phase liquid are unlikely because of the high viscosity of treated Series 743 waste. 1,4-dioxane also has a low sorption coefficient ( $K_{oc}$ ), meaning it is most likely to exist as an aqueous phase dissolved in soil water.

Until recently, 1,4-dioxane received little attention from regulating authorities. The EPA has not included it in the target compound list or the priority pollutant list, nor has it established an MCL for drinking water. However, the EPA has identified 1,4-dioxane as a probable human carcinogen B2 and issued a health-based advisory level of 3 µg/L for drinking water.

1,4-dioxane was not included in analyte lists for groundwater, perched water, or vadose zone lysimeter samples at RWMC. The only available analyses for 1,4-dioxane are for waste zone lysimeter samples collected since the third quarter of FY 2005. No 1,4-dioxane data are available for the vadose zone and aquifer.

### 4.23.1 Waste Zone

**4.23.1.1 Inventory and Distribution.** An estimated 1.95E+03 kg of 1,4-dioxane was buried in the SDA (see Table 4-7). The majority (88.2%) of the 1,4-dioxane is contained in Series 743 sludge from the Rocky Flats Plant. Varvel (2006) estimated the 1,1,1-trichloroethane inventory contained 2.75% by volume 1,4-dioxane. Figure 4-26 illustrates the density of 1,4-dioxane in buried waste.

**4.23.1.2 Waste Zone Soil-Gas Data from Type B Probes.** Waste zone soil-gas samples have not been analyzed for 1,4-dioxane.

**4.23.1.3 Waste Zone Lysimeter Data.** Lysimeter samples from the waste zone are not routinely analyzed for organic contaminants because of limited sample volumes and analytical priorities. In addition, only samples collected since June 2005 have been analyzed for 1,4-dioxane. Data collected after 2004 is not presented for other organic contaminants; however, because the only data that exist for 1,4-dioxane was collected in 2005, it is discussed here. Table 4-95 shows the dioxane results for the last two quarters of FY 2005. The waste zone lysimeter locations are shown in Figure 4-35.

Two of five waste zone lysimeter samples had positive detections for 1,4-dioxane. The maximum concentration (728,000 µg/L) is approximately 250,000 times greater than the health-based advisory level of 3 µg/L. In general, the results agree with disposal location information in that concentrations correspond to the density of Series 743 waste burials. Recall that nearly 90% of the 1,4-dioxane inventory is in Series 743 sludge. The concentration was very high in the sample from Lysimeter P6-PU-L1, which is in a high-density Series 743 waste disposal location. The lysimeter in Pit 5 (P5-UEU-L1) is also located near Series 743 waste, but the Series 743 waste density in this area is not as high as Pit 6. This may explain why the result is positive, but not as high as the Pit 6 lysimeter result. The lysimeter in the Series 741 Focus Area in Pit 10 (741-08-L6) is in a low-density Series 743 waste disposal area, and

Table 4-95. 1,4-dioxane results from waste zone lysimeter samples.

Lysimeter	Depth (ft)	Concentration (µg/L)	Qualifier or Validation Flag <sup>a</sup>	Dilution Factor	Date
P5-UEU-L1	16.6	981	J	1	6/20/2005
P5-UEU-L1	16.6	648 <sup>b</sup>	J	25	6/20/2005
T3-EU-L1	9.7	<50	U	1	6/20/2005
741-08-L6	8.8	<250	U	1	7/21/2005
P6-PU-L1	15.2	728,000	J, E	500	7/21/2005
T3-EU-L1	9.7	< 50	U	1	9/13/2005

a. Qualifier/validation flag explanation:

- J indicates the assigned concentration is an estimated value
- U indicates the analyte was not detected. The numerical value is the sample quantitation limit
- E indicates the result exceeded the calibration range of the instrument.

b. Duplicate analysis with dilution.

1,4-dioxane was not detected above a quantitation limit of 250 µg/L. The other lysimeter (T3-EU-L2) is located near Trench 3 in the western portion of the SDA. No Series 743 waste disposals are located in this area, and this correlates with the nondetect result.

#### 4.23.2 Surface

Samples of surface soil, vegetation, and run-off water are not analyzed for VOCs. Also, gaseous emission data from the soil surface have not been analyzed for 1,4-dioxane.

#### 4.23.3 Vadose Zone

Vadose zone soil-gas, perched water, and lysimeter samples have not been analyzed for 1,4-dioxane.

#### 4.23.4 Aquifer

Aquifer samples have not been analyzed for 1,4-dioxane.

#### 4.23.5 Summary for 1,4-Dioxane

1,4-dioxane was positively detected in two of five waste zone lysimeter samples. The results are strongly correlated to Series 743 waste disposal density. The maximum measured concentration was 728,000 µg/L, approximately 250,000 times the health-based advisory level.

Because no analyses of waste zone soil-gas, perched water, lysimeter, or aquifer samples were performed for 1,4-dioxane, no three-dimensional summary figure is provided.

## 4.24 Methylene Chloride (Volatile Organic Compound)

Methylene chloride, or dichloromethane, is an ingredient in many industrial compounds, including solvents, paint and varnish removers, degreasing agents for metal parts, aerosols, refrigerants, and a blowing agent in foams. Methylene chloride can exist in various forms, including a nonaqueous-phase liquid, a vapor phase in soil gas, an aqueous phase dissolved in soil water, and a solid phase sorbed onto soil particles. In the environment, methylene chloride will partition into all the phases, seeking an equilibrium condition. At the SDA, however, all the methylene chloride came from weapons-production processes at the Rocky Flats Plant. More than half was contained in uncemented sludge (i.e., Series 741), while the remainder was associated with trash and debris. Significant quantities of nonaqueous-phase liquid are unlikely because cement and Oil-Dri were added to bind any liquid and stabilize the sludge. Soil also is an insignificant medium at the SDA because methylene chloride is a highly volatile organic compound that tends to vaporize. Therefore, the nature and extent of methylene chloride in soil gas and water are the focus of discussions that follow. This section presents sampling results for methylene chloride in soil gas, soil moisture, and the aquifer. Sampling data in this section are evaluated against comparison concentrations shown in Table 4-1. Soil-gas remediation goals were not established by the OCVZ Project for methylene chloride.

### 4.24.1 Waste Zone

**4.24.1.1 Inventory.** Inventory records indicate  $1.41\text{E}+04$  kg of methylene chloride was buried in the SDA (see Table 4-7), mostly in sludge. Because carbon tetrachloride can degrade to methylene chloride, detections of methylene chloride in environmental samples could be related either to the original inventory buried in the SDA or to degradation of carbon tetrachloride. Figure 4-27 shows the density of methylene chloride in buried waste based on original disposals (i.e., without accounting for potential degradation of carbon tetrachloride).

**4.24.1.2 Waste Zone Soil-Gas Data from Type B Probes.** The Innova photoacoustic multigas analyzer used to analyze the Type B vapor probe samples is not set up to analyze for methylene chloride. The duplicate samples sent to the laboratory, however, are analyzed for methylene chloride by gas chromatography and mass spectrometry methods. In general, methylene chloride detections are infrequent. Of 23 samples analyzed since 2002, only five returned a positive detection for methylene chloride; and in two of those samples, it was not detected in a duplicate. The maximum methylene chloride detection was 980 ppmv in a sample collected from Probe 743-08-VP1 on September 27, 2004. This is one of the samples that did not detect methylene chloride in the duplicate.

### 4.24.2 Surface

Surface soil, vegetation, and run-off water samples are not analyzed for VOCs. However, gaseous emissions from the soil surface of the SDA were collected in December 1992 and July 1993 using a surface isolation flux chamber. Measurements were made in the 12 locations indicated in Figure 4-80. Methylene chloride emissions were detected in five of the 12 locations. The maximum emission rate for methylene chloride was  $1.2 \mu\text{g}/\text{m}^2/\text{minute}$  in December 1992 at location FC-12 near Pit 15. Duncan, Sondrup, and Troutman (1993) and Schmidt (1993) record complete results of these studies.

### 4.24.3 Vadose Zone

Methylene chloride has been detected at low levels in the vadose zone. This section discusses the vadose zone sample results including soil-gas data, perched water data, and lysimeter data.

**4.24.3.1 Soil-Gas Data.** Since 1993, vadose zone soil-gas samples have not been routinely analyzed for methylene chloride. Of the samples collected before 1993, several hundred were analyzed for methylene chloride, and only five returned positive detections. One of the samples was collected from Well TEM1-A in April 1993 at a depth of 0.61 m (2 ft). The other four samples were collected from Well 8801 in September 1991. Two of the samples from Well 8801 were collected from Port 4 at a depth of 23.6 m (77.5 ft), and the other two samples were collected from Port 5 at a depth of 28.2 m (92.5 ft). Though samples from Well 8801 were reported as positive detections, they should be viewed with caution because of high dilution factors. A summary of these results is given in Table 4-96.

Table 4-96. Summary of positive detections of methylene chloride in soil-gas samples collected near the Subsurface Disposal Area.

Well Name-Port	Sample Depth (ft)	Soil-Gas Concentration (ppmv)	Dilution Factor <sup>a</sup>	Date
TEM1A	2	2	2	April 1993
8801-4	77.5	70	400	September 1991
		184	400	September 1991
8801-4	92.5	15	100	September 1991
		57	200	September 1991

a. Concentrations are adjusted for dilution factors. High dilution factors increase uncertainty in reported concentrations.

**4.24.3.2 Perched Water Data.** Methylene chloride has been detected in 10 of 14 perched water samples from Well USGS-92. The maximum concentration measured was 23 µg/L on April 17, 1997. A concentration of 86 µg/L was estimated (J-flag qualifier) in August 1997, but the result is questionable because of the very large dilution factor (i.e., 200) used. Single perched water samples from Wells 8802 (February 1998) and D10 (August 1992) were analyzed for methylene chloride, but it was not detected in either sample.

**4.24.3.3 Lysimeter Data.** Methylene chloride was positively identified in 10 of 43 lysimeter samples collected between 1997 and 2000. Lysimeter samples have not been analyzed for organic contaminants since September 2000 because of limited sample volumes and analytical priorities. Of the 10 samples with positive detections, seven were J-flagged, indicating the compound was present, but the concentration could only be estimated. Shallow lysimeters with positive detections include W06-L27, W08-L14, W23-L09, W25-L28, PA01-L15, and PA02-L16. The maximum methylene chloride concentration measured was 16 µg/L in Lysimeter PA02-L16 at a depth of 3 m (11 ft) on September 11, 2000. Lysimeter locations are shown in Figures 4-41, 4-42, and 4-43.

#### 4.24.4 Aquifer

Methylene chloride has been detected in eight aquifer wells in the vicinity of RWMC. Of hundreds of samples, only 18 detections have occurred, and 15 of those were assigned a J-qualifier, indicating the assigned concentration was estimated. Results associated with methylene chloride in the associated laboratory blank were not classified as detections. The maximum concentration measured was 6 µg/L in Well M1S on February 25, 1993; however, this concentration is suspicious because it is much greater than any other detection. Table 4-97 contains the three detections not assigned a J-qualifier.

Table 4-97. Summary of methylene chloride detections in the aquifer.

Aquifer Well	Concentration (µg/L)	Date
M1S	6	February 1993
M7S	1	March 1993
M7S	2	November 1993

#### 4.24.5 Summary of Methylene Chloride

Methylene chloride has been infrequently and inconsistently detected at RWMC in vadose zone soil gas, vadose zone soil water (perched water and lysimeters), and the aquifer. Since 1993, however, vadose zone soil-gas samples have not been analyzed for methylene chloride, and only duplicate waste zone soil-gas samples are analyzed for methylene chloride.

Methylene chloride has been detected in only five of 23 waste zone soil-gas samples; in two of those detections, it was not identified in the duplicate. The maximum concentration measured was 980 ppmv, but it was also found in the associated laboratory blank for that sample round. In perched water, methylene chloride has been detected in 10 of 16 samples, and two of those detections were assigned a J-flag qualifier. Methylene chloride was detected in 10 of 43 lysimeter samples collected between 1997 and 2000, but seven of those detections were assigned a J-flag qualifier. The maximum lysimeter concentration was 16 µg/L in Lysimeter PA02-L16 at a depth of 3 m (11 ft) in 2000.

In the aquifer, methylene chloride has been detected in three of 22 wells in the vicinity of RWMC. Methylene chloride has been detected one time greater than the MCL of 5 µg/L without a data qualifier, and that was 6 µg/L in Well M1S in 1993. Table 4-98 shows the detection frequencies for methylene chloride in aqueous samples from the vadose zone and aquifer. Aquifer statistics do not include data from USGS wells.

Table 4-98. Methylene chloride detection frequencies for aqueous samples.

Media	Number of Detections	Detection Rate (%)	Range of Detected Concentrations (µg/L) <sup>a</sup>	Total Number of Detections Greater Than Maximum Contaminant Level <sup>a,b</sup>	Wells with Detections Greater Than Maximum Contaminant Level <sup>b</sup>
<b>Vadose zone soil moisture</b>					
Soil moisture (0 to 35 ft)	10	26	3 to 16	8	PA01-L15, PA02-L16, W08-L14, W23-L09, W25-L28
Soil moisture (35 to 140 ft)	0	0	NA	0	None
Soil moisture (>140 ft)	0	0	NA	0	None
Perched water	11	73	0.2 to 23	5	USGS-92
<b>Aquifer soil moisture</b>					
Idaho National Laboratory Site wells only (since 1992)	18 <sup>c</sup>	4	0.2 to 6	1	M1S

a. Estimated data assigned a J-flag qualifier were excluded when determining the range of detected concentrations; however, they were included when determining the number of detections greater than the MCL.

b. The MCL is 5 µg/L used for comparison.

c. Does not include samples with a B qualifier (contaminant also found in the associated laboratory sample blank). Only three of the 18 detections did not have a J qualifier.

MCL = maximum contaminant level

## 4.25 Tetrachloroethylene (Volatile Organic Compound)

Tetrachloroethylene is a manufactured chemical widely used for dry cleaning fabrics and degreasing metal. Like carbon tetrachloride, tetrachloroethylene can exist as a nonaqueous-phase liquid, a vapor phase in soil gas, an aqueous phase dissolved in soil water, and a solid phase sorbed onto soil particles. In the environment, tetrachloroethylene will partition into all the phases, seeking an equilibrium condition. All of the tetrachloroethylene buried in the SDA came from Series 743 sludge generated by weapons-production processes at Rocky Flats Plant. Significant quantities of nonaqueous-phase liquid are unlikely because of the high viscosity of the treated Series 743 waste. Soil also is an insignificant medium at the SDA because tetrachloroethylene is a VOC that tends to vaporize. Therefore, the nature and extent of tetrachloroethylene in soil gas and water are the focus of discussions that follow. This section presents sampling results for tetrachloroethylene in soil gas, soil moisture, and the aquifer. Sampling data in this section are evaluated against comparison concentrations shown in Table 4-1. Soil-gas remediation goals were not established by the OCVZ Project for tetrachloroethylene.

Tetrachloroethylene has been detected at RWMC in soil gas, vadose zone soil water (perched water and lysimeters), and the aquifer. Tetrachloroethylene vapor also has been detected emanating from the soil surface by surface isolation flux chambers. An examination of tetrachloroethylene data shows distribution and trends are similar to those for carbon tetrachloride data, but tetrachloroethylene concentrations are much less because of the smaller inventory. Distribution and trends are similar because both compounds come from the same waste stream, and they have similar chemical and transport properties. The two compounds also are similar from a toxicological standpoint. Because of these similarities and because carbon tetrachloride data are described extensively in Section 4.22, this section is a limited presentation of tetrachloroethylene data.

### 4.25.1 Waste Zone

**4.25.1.1 Inventory and Distribution.** Approximately  $9.87\text{E}+04$  kg of tetrachloroethylene was buried in SDA Pits 4, 5, 6, 9, and 10 in Series 743 waste (see Table 4-7). Varvel (2006) calculated the amount of tetrachloroethylene in Series 743 waste by assuming the non-carbon tetrachloride fraction of VOCs estimated by Miller and Varvel (2005) contained equal volumes of tetrachloroethylene, trichloroethylene, and 1,1,1-trichloroethane. Density of tetrachloroethylene in buried waste is illustrated in Figure 4-28.

**4.25.1.2 Waste Zone Soil-Gas Data from Type B Probes.** Table 4-99 contains the maximum tetrachloroethylene concentrations as measured with the Innova multi-gas analyzer for the eight probes that consistently yielded a sample (see Section 4.22.1.2). As expected, tetrachloroethylene concentrations in the waste zone are greater than concentrations measured in the vadose zone and are indicative of relatively fresh sludge because the values exceed the predicted equilibrium concentration of tetrachloroethylene for the Series 743 sludge mixture (750 ppmv) (Myers et al. 2004). During the 4 years of sampling (2002 to 2005), concentrations have remained fairly steady.

**4.25.1.3 Waste Zone Lysimeter Data.** Lysimeter samples from the waste zone are not routinely analyzed for organic contaminants because of limited sample volumes and analytical priorities. However, in December 2004, a liquid sample was collected from Lysimeter DU-14-L3 in the waste zone in the western end of Pit 10. The sample had an oily appearance and a petroleum-like odor. The sample was analyzed for organic contaminants but after the 14-day holding time limit specified by the analytical method. The tetrachloroethylene concentration in the sample was 130 g/L. This is more than 500 times the solubility limit, indicating the sample contained liquid tetrachloroethylene. The tetrachloroethylene concentration was also uncharacteristically greater than the carbon tetrachloride result. This is probably from the extended holding time and because tetrachloroethylene is less volatile than carbon tetrachloride.

Table 4-99. Maximum tetrachloroethylene vapor concentrations from Type B vapor probes.

Vapor Port	Port Depth (ft)	Maximum Tetrachloroethylene Concentration (ppmv)	Date
743-08-VP1	20.2	3,680	2/17/2004
743-08-VP2	13.4	2,630	2/17/2004
743-18-VP4	14.6	218	2/12/2002
DU-08-VP2	15.8	2,331	6/11/2002
DU-10-VP2	10.0	2,129	8/20/2002
DU-10-VP3	6.2	2,942	8/15/2002
DU-14-VP2	11.7	1,010	9/27/2004
DU-14-VP3	4.9	986	8/15/2002

#### 4.25.2 Surface

Surface soil, vegetation, and run-off water samples are not analyzed for VOCs. However, gaseous emissions from the SDA soil surface were collected in December 1992 and July 1993 using a surface isolation flux chamber. Measurements were made in the 12 locations indicated in Figure 4-80. Tetrachloroethylene emissions were detected in six of the 12 locations. The maximum emission rate for tetrachloroethylene was  $8.2 \mu\text{g}/\text{m}^2/\text{minute}$  in July 1993 at location FC-5 between Pits 4 and 10. This is the same location where the maximum carbon tetrachloride and trichloroethylene emission was measured. Duncan, Sondrup, and Troutman (1993) and Schmidt (1993) record complete results of these studies.

#### 4.25.3 Vadose Zone

Tetrachloroethylene has been detected in vadose zone soil gas and in perched water and lysimeter samples. The tetrachloroethylene results are consistent with the carbon tetrachloride results in that they are generally less than the carbon tetrachloride results by the ratio of the inventories. The tetrachloroethylene inventory is approximately an order of magnitude less than the carbon tetrachloride inventory, and the tetrachloroethylene sample results are less than the carbon tetrachloride results by about the same margin. As a result, many of the tetrachloroethylene sample results are less than detection limits in areas where carbon tetrachloride concentrations are low.

**4.25.3.1 Soil-Gas Data.** Tetrachloroethylene has been detected in soil gas from land surface to the aquifer. The highest tetrachloroethylene soil-gas concentration measured inside the SDA was 135 ppmv in Well 8902 Port 4 at a depth of 39 m (130 ft) on January 4, 1996. This compares to a maximum carbon tetrachloride soil-gas concentration of 4,864 ppmv in Well 9302 Port 6 at a depth of 23 m (77 ft). Since April 1998, tetrachloroethylene concentrations in Well 8902 Port 4 have been less than 10 ppmv. The reduction in concentration is attributed to operation of the vapor vacuum extraction with treatment system. Concentrations at other wells inside the SDA are generally less than 20 ppmv. Concentrations are less than 2 ppmv below the C-D interbed inside the SDA. Outside the SDA, concentrations are less than the inside concentrations by about an order of magnitude for similar depths. Figure 4-114 contains three-dimensional figures showing average tetrachloroethylene vapor concentrations in the SDA subsurface in 2004.



**4.25.3.2 Perched Water Data.** Tetrachloroethylene has been detected in perched water samples from Wells USGS-92, 8802D, and D10 located inside the SDA. The highest concentration (i.e., 230 µg/L) was detected in Well USGS-92 in 1992. For comparison, the highest carbon tetrachloride concentration was 2,400 µg/L measured in the same sample. In general, the tetrachloroethylene concentrations are less than carbon tetrachloride by about one order of magnitude.

Like carbon tetrachloride, tetrachloroethylene concentrations in perched water have decreased in response to operation of the vapor vacuum extraction with treatment system. This is shown in Table 4-100, which contains tetrachloroethylene concentrations measured in perched water over time. Before full-scale operation of the vapor vacuum extraction with treatment system began in 1996, tetrachloroethylene concentrations in perched water from Well USGS-92 ranged from 110 to 230 µg/L. Since that time, concentrations have been less than 125 µg/L. Concentrations in Well USGS-92 respond directly to operation of the vapor vacuum extraction system because Well 7V (a vapor extraction well) is located near Well USGS-92. As soil gas containing tetrachloroethylene vapor is removed by vapor extraction, tetrachloroethylene in the perched water partitions into the surrounding soil gas to maintain an equilibrium ratio.

Table 4-100. Tetrachloroethylene data for perched water samples at the Subsurface Disposal Area.

Perched Water Well	Depth <sup>a</sup> (ft)	Concentration (µg/L)	Date
USGS-92	214	110	October 1987
		120	April 1988
		180	April 1992
		230	August 1992
		<180	February 1996
		110	April 1997
		26	April 1997
		81 J <sup>b</sup>	August 1997
		5	February 1998
		50	March 1998
		23	March 1999
		43	April 2000
		125	April 2001
		30	April 2002
8802D	220	40	April 2003
		7	July 1989
		13	August 1992
		3	February 1998
D10	238	5	August 1992

a. Depths of open or screened intervals are as follows:

- USGS-092: 19 to 214 ft
- 8802D: 211 to 221 ft
- D10: 220 to 238 ft.

b. J-flag qualifier indicates the assigned concentration is an estimated value.

**4.25.3.3 Lysimeter Data.** Tetrachloroethylene was detected in 22 of 43 lysimeter samples collected between 1997 and 2000. Lysimeter samples have not been analyzed for organic contaminants since September 2000 because of limited sample volumes and analytical priorities. Shallow lysimeters with positive detections include W08-L13, W23-L08, W23-L09, W25-L28, PA01-L15, and PA02-L16. Tetrachloroethylene also was detected once in an intermediate-depth lysimeter, D06-DL02 (13.4 m [44 ft]), and a deep lysimeter, I3D-DL12 (71 m [233 ft]). The maximum tetrachloroethylene concentration measured, excluding estimated values (i.e., J-flagged data) was 27 µg/L in Lysimeter W23-L08 at a depth of 3 m (11 ft) on August 3, 1998. Tetrachloroethylene results for intermediate and deep lysimeters, D06-DL02 and I3D-DL12, were 12 and 22 µg/L, respectively. For comparison, the maximum carbon tetrachloride concentration in a lysimeter was 1,000 µg/L in Lysimeter D06-DL02. Lysimeter locations are shown in Figures 4-41, 4-42, and 4-43.

#### **4.25.4 Aquifer**

Positive detections of tetrachloroethylene in RWMC-vicinity aquifer wells are infrequent. The maximum tetrachloroethylene concentration measured was 0.5 µg/L in Well M7S on July 14, 1997. Subsequently, the maximum tetrachloroethylene concentration was 0.3 µg/L in 2002, 2003, and 2004, all from the RWMC Production Well. These concentrations are well below the MCL of 5 µg/L. For comparison, the maximum carbon tetrachloride concentration measured in the aquifer was 8 µg/L in Well M7S. Again, the tetrachloroethylene results for groundwater are less than the carbon tetrachloride results by approximately one order of magnitude.

#### **4.25.5 Summary for Tetrachloroethylene**

Tetrachloroethylene has been detected at RWMC in vadose zone soil gas, vadose zone soil water (perched water and lysimeters), and the aquifer. Tetrachloroethylene monitoring data show distribution and trends similar to carbon tetrachloride, but concentrations are much less. The distribution is similar because both compounds come from the same waste stream and have similar chemical and transport properties. Tetrachloroethylene concentrations are less because the inventory compared to carbon tetrachloride is much smaller.

In vadose zone soil gas and the aquifer, tetrachloroethylene concentrations are approximately one order of magnitude less than carbon tetrachloride concentrations. The maximum tetrachloroethylene vapor concentration measured was 3,680 ppmv from a probe in the waste zone. In the vadose zone, vapor concentrations range from about 100 ppmv in the center of the SDA and decrease with depth and distance away. In the aquifer, positive detections of tetrachloroethylene are infrequent. The maximum concentration measured in the aquifer was 0.7 µg/L in Well M7S. Although data are limited, aquifer concentrations have been quite stable. During the past 3 years, the maximum aquifer concentration was 0.3 µg/L in the RWMC Production Well. The vapor vacuum extraction with treatment system has reduced tetrachloroethylene vapor concentrations in the vadose zone significantly since it began operation in 1996. Table 4-101 shows detection frequencies for tetrachloroethylene in aqueous samples from the vadose zone and aquifer. Aquifer statistics do not include data from USGS wells.

Table 4-101. Tetrachloroethylene detection frequencies for aqueous samples.

Media	Number of Detections	Detection Rate (%)	Range of Detected Concentrations (µg/L) <sup>a</sup>	Total Number of Detections Greater Than Maximum Contaminant Level <sup>a,b</sup>	Wells with Detections Greater Than Maximum Contaminant Level <sup>b</sup>
<b>Vadose zone soil moisture</b>					
Soil moisture (0 to 35 ft)	19	49	2 to 27	17	PA01-L15, PA02-L16, W23-L08, W23-L09, W25-L28
Soil moisture (35 to 140 ft)	1	50	12	1	D06-DL02
Soil moisture (>140 ft)	2	100	22 <sup>c</sup>	2	I3D-DL12
Perched water	18	100	3 to 230	16	USGS-92, 8802
<b>Aquifer soil moisture</b>					
Idaho National Laboratory Site wells only (since 1992)	60	12	0.2 to 0.5 <sup>d</sup>	0	None

a. Estimated data assigned a J-flag qualifier were excluded when determining the range of detected concentrations. However, they were included when determining the number of detections greater than the MCL.

b. MCL used for comparison is 5 µg/L.

c. One of two detections was estimated (J-flagged data).

d. All 60 detections are estimated concentrations (J-flagged data).

MCL = maximum contaminant level

## 4.26 Trichloroethylene (Volatile Organic Compound)

Trichloroethylene is a manufactured chemical widely used as a solvent for degreasing metal. It is also a common ingredient in paint, paint strippers, and varnishes. Like carbon tetrachloride and tetrachloroethylene, trichloroethylene can exist as a nonaqueous-phase liquid, a vapor phase in soil gas, an aqueous phase dissolved in soil water, and a solid phase sorbed onto soil particles. In the environment, trichloroethylene will partition into all the phases, seeking an equilibrium condition. Nearly all trichloroethylene buried in the SDA is from Series 743 waste generated by weapons-production processes at Rocky Flats Plant. Significant quantities of a nonaqueous-phase liquid are unlikely because of the high viscosity of the treated Series 743 sludge. Soil also is an insignificant medium at SDA because trichloroethylene is a VOC that tends to vaporize. Therefore, the nature and extent of trichloroethylene in soil gas and water are the focus of discussions that follow. This section presents sampling results for trichloroethylene in soil gas, soil moisture, and the aquifer. Sampling data in this section are evaluated against comparison concentrations shown in Table 4-1. Soil-gas remediation goals have been established by Operable Unit 7-08 for carbon tetrachloride, but not for trichloroethylene.

Trichloroethylene has been detected at RWMC in soil gas, vadose zone soil water (perched water and lysimeter samples), and groundwater. Trichloroethylene vapor also has been detected emanating from the soil surface by surface isolation flux chambers. An examination of trichloroethylene data shows distribution and trends are similar to those for carbon tetrachloride data, but trichloroethylene concentrations are less due to a smaller inventory. Distribution and trends are similar because both compounds come primarily from the same waste stream and have similar chemical and transport properties. The two compounds also are similar from a toxicological standpoint. Because of these similarities and because carbon tetrachloride data are described extensively in Section 4.22, this section is a limited presentation of trichloroethylene data.

### 4.26.1 Waste Zone

**4.26.1.1 Inventory and Distribution.** An estimated  $8.96\text{E}+04$  kg of trichloroethylene was buried in the SDA (see Table 4-7); 99.4% of the trichloroethylene was buried in Pits 4, 5, 6, 9, and 10 as Series 743 waste. Varvel (2006) calculated the amount of trichloroethylene in Series 743 waste by assuming the non-carbon tetrachloride fraction of VOCs estimated by Miller and Varvel (2005) contained equal volumes of tetrachloroethylene, trichloroethylene, and 1,1,1-trichloroethane. The density of trichloroethylene in buried waste is illustrated in Figure 4-29.

**4.26.1.2 Waste Zone Soil-Gas Data from Type B Probes.** Table 4-102 illustrates the maximum trichloroethylene concentrations as measured with the Innova multi-gas analyzer for the eight vapor probes that consistently yielded a sample (see Section 4.22.1.2). As expected, trichloroethylene concentrations in the waste zone are greater than concentrations measured in the vadose zone and are indicative of relatively fresh sludge because the values are near or exceed the predicted equilibrium concentration of trichloroethylene for the Series 743 sludge mixture (3,900 ppmv) (Myers et al. 2004). During the 4 years of sampling (2002 to 2005), vapor concentrations from waste zone probe samples remained fairly steady.

Table 4-102. Maximum trichloroethylene vapor concentrations from Type B vapor probes.

Vapor Port	Port Depth (ft)	Maximum Trichloroethylene Concentration (ppmv)	Date
743-08-VP1	20.2	10,080	8/20/2002
743-08-VP2	13.4	4,040	2/17/2004
743-18-VP4	14.6	2,740	12/13/2004
DU-08-VP2	15.8	8,860	11/18/2002
DU-10-VP2	10.0	4,266	8/20/2002
DU-10-VP3	6.2	4,259	8/15/2002
DU-14-VP2	11.7	10,200	11/18/2002
DU-14-VP3	4.9	2,620	12/22/2004

**4.26.1.3 Waste Zone Lysimeter Data.** Lysimeter samples from the waste zone are not routinely analyzed for organic contaminants because of limited sample volumes and analytical priorities. However, in December 2004, a liquid sample was collected from Lysimeter DU-14-L3 in the waste zone in the western end of Pit 10. The sample had an oily appearance and a petroleum-like odor. The sample was analyzed for organic contaminants, but after the 14-day holding time limit specified by the analytical method. The trichloroethylene concentration in the sample was 130 g/L. This is nearly 100 times the solubility limit, indicating the sample contained liquid trichloroethylene. The trichloroethylene concentration was also unexpectedly greater than the carbon tetrachloride result. This is probably due to the extended holding time and because trichloroethylene is less volatile than carbon tetrachloride.

#### 4.26.2 Surface

Samples of surface soil, vegetation, and run-off water are not analyzed for VOCs. However, gaseous emissions from the SDA soil surface were collected in December 1992 and July 1993 using a surface isolation flux chamber. Measurements were made in the 12 locations indicated in Figure 4-80. Trichloroethylene emissions were detected in six of the 12 locations. The maximum emission rate for trichloroethylene was 15  $\mu\text{g}/\text{m}^2/\text{minute}$  in July 1993 at location FC-5 between Pits 4 and 10. This is the same location where the maximum carbon tetrachloride and tetrachloroethylene emission was measured. Duncan, Sondrup, and Troutman (1993) and Schmidt (1993) record complete results of these studies.

#### 4.26.3 Vadose Zone

Trichloroethylene has been detected in vadose zone soil gas and in perched water and lysimeter samples. The trichloroethylene results are generally less than the carbon tetrachloride results due to the smaller inventory.

**4.26.3.1 Soil-Gas Data.** Trichloroethylene has been detected in soil gas from land surface to the aquifer. The highest trichloroethylene soil-gas concentration measured inside the SDA was 810 ppmv in Well 8801 Port 4 at a depth of 24 m (78 ft) in 1992. This compares to a maximum carbon tetrachloride soil-gas concentration of 4,864 ppmv in Well 9302 Port 6 at a depth of 23 m (77 ft) in 1995. Inside the SDA, trichloroethylene concentrations have declined in response to operation of the Operable Unit 7-08 vapor vacuum extraction with treatment system, but continue to show significant rebound near source

areas when the system is shut down. Currently, trichloroethylene vapor concentrations inside the SDA above the B-C interbed are approximately 200 to 500 ppmv near source areas and less than 100 ppmv away from the source areas. Between the B-C and C-D interbeds, concentrations range from 20 to 200 ppmv. Below the C-D interbed, the concentrations are generally less than 20 ppmv. Outside the SDA, concentrations are less than the inside concentrations by about an order of magnitude for similar depths. Figure 4-116 contains three-dimensional figures showing average trichloroethylene vapor concentrations in the SDA subsurface in 2004.

**4.26.3.2 Perched Water Data.** Trichloroethylene has been detected in perched water samples from Wells USGS-92, 8802D, and D10 located inside the SDA. The highest concentration (1,600 µg/L) was detected in Well USGS-92 in 1992. For comparison, the highest carbon tetrachloride concentration was 2,400 µg/L measured in the same sample. In general, trichloroethylene concentrations in perched water measure about 75% of the carbon tetrachloride concentrations.

Like carbon tetrachloride, trichloroethylene concentrations in perched water have decreased in response to operation of the vapor vacuum extraction with treatment system, as shown in Table 4-103, which contains trichloroethylene concentrations measured in perched water over time. Before full-scale operation of the vapor vacuum extraction with treatment system began in 1996, trichloroethylene concentrations in perched water from Well USGS-92 ranged from 860 to 1,600 µg/L. Since that time, concentrations have been less than 800 µg/L. Concentrations in Well USGS-92 respond directly to operation of the vapor vacuum extraction system because Well 7V (a vapor extraction well) is located near Well USGS-92. As soil gas containing trichloroethylene vapor is removed by vapor extraction, trichloroethylene in the perched water partitions into the surrounding soil gas to maintain an equilibrium ratio.

Table 4-103. Trichloroethylene data for perched water samples at the Subsurface Disposal Area.

Perched Water Well	Depth <sup>a</sup> (ft)	Concentration (µg/L)	Date
USGS-92	214	860	October 1987
		1,100	April 1988
		1,500	April 1992
		1,600	August 1992
		1,400	February 1996
		786	April 1997
	190	190	April 1997
		560 J <sup>b</sup>	August 1997
		34	February 1998
		360	March 1998
		179	March 1999
		280	April 2000
	798 B <sup>c</sup>	798 B <sup>c</sup>	April 2001
		198 B <sup>c</sup>	April 2002
		232 B <sup>c</sup>	April 2003

Table 4-103. (continued).

Perched Water Well	Depth <sup>a</sup> (ft)	Concentration (µg/L)	Date
8802D	220	97	July 1989
		150	August 1992
		26	February 1998
D10	238	14	August 1992

a. Depths of open or screened intervals are as follows:

- USGS-092: 19 to 214 ft
- 8802D: 211 to 221 ft
- D10: 220 to 238 ft.

b. J-flag qualifier indicates the assigned concentration is an estimated value.

c. B-flag indicates compound was also detected in the associated laboratory blank.

**4.26.3.3 Lysimeter Data.** Trichloroethylene was detected in 31 of 43 lysimeter samples collected between 1997 and 2000. Lysimeter samples have not been analyzed for organic contaminants since September 2000 because of limited sample volumes and analytical priorities. Shallow lysimeters with positive detections include W05-L26, W06-L37, W08-L13, W08-L14, W23-L08, W23-L09, W25-L28, PA01-L15, PA02-L16, and 98-5-L39. Trichloroethylene also was detected in an intermediate-depth lysimeter, D06-DL02 (13.4 m [44 ft]), and a deep lysimeter, I3D-DL12 (71 m [233 ft]). The maximum trichloroethylene concentration measured in a lysimeter—excluding estimated values (i.e., J-flagged data)—was 670 µg/L in Lysimeter D06-DL02 on April 29, 1997. For comparison, the maximum carbon tetrachloride concentration was 1,000 µg/L in the same lysimeter. Lysimeter locations are shown in Figures 4-41, 4-42, and 4-43.

#### 4.26.4 Aquifer

Aquifer samples collected in many RWMC-vicinity aquifer wells routinely test positive for trichloroethylene. The maximum trichloroethylene concentration measured in the aquifer was 3.9 µg/L in Well USGS-90 on January 19, 1988. Since 2000, the highest concentrations measured have been 3.3, 3.2, and 3.0 µg/L in Wells RWMC Production, A11A31, and M7S, respectively. Trichloroethylene has not been detected in the aquifer greater than the MCL of 5 µg/L, and concentrations appear to be relatively stable.

#### 4.26.5 Summary for Trichloroethylene

Trichloroethylene has been detected at RWMC in vadose zone soil gas, vadose zone soil water (perched water and lysimeters), and the aquifer. Trichloroethylene monitoring data show distribution and trends similar to carbon tetrachloride, but concentrations are less. The distribution is similar because both compounds originate from the same waste stream and have similar chemical and transport properties. Trichloroethylene concentrations are less, primarily because the inventory is smaller compared to carbon tetrachloride.

The maximum trichloroethylene vapor concentration measured in vadose zone soil gas was 10,200 ppmv from a probe in the waste zone. Vapor concentrations in the vadose zone range from several hundred ppmv in the center of the SDA and decrease with depth and distance. The vapor vacuum extraction with treatment system has reduced trichloroethylene vapor concentrations in the vadose zone since it began operation in 1996.

In the aquifer, positive detections of trichloroethylene occur regularly in all but four wells. However, since monitoring began in 1987, trichloroethylene has not been detected in the aquifer greater than the MCL of 5 µg/L. The maximum concentration measured in the aquifer was 3.9 µg/L in Well USGS-90. Only three other wells have measured concentrations equal to or greater than 3 µg/L. Table 4-104 shows detection frequencies for trichloroethylene in aqueous samples from the vadose zone and aquifer. Aquifer statistics do not include data from USGS wells.

Table 4-104. Trichloroethylene detection frequencies for aqueous samples.

Media	Number of Detections	Detection Rate (%)	Range of Detected Concentrations (µg/L) <sup>a</sup>	Total Number of Detections Greater Than Maximum Contaminant Level <sup>a,b</sup>	Wells with Detections Greater Than Maximum Contaminant Level <sup>b</sup>
<b>Vadose zone soil moisture</b>					
Soil moisture (0 to 35 ft)	31	79	0.5 to 450	29	PA01-L15, PA02-L16, W05-L26, W06-L27, W08-L13, W08-L14, W23-L08, W23-L09, W25-L28, 98-5-L39
Soil moisture (35 to 140 ft)	2	100	670	2	D06-DL02
Soil moisture (>140 ft)	2	100	450	2	I3D-DL12
Perched water	18	100	14 to 1,600	18	USGS-92, 8802, D10
<b>Aquifer soil moisture</b>					
Idaho National Laboratory Site wells only (since 1992)	260	48	0.2 to 3.2	0	None

a. Estimated data assigned a J-flag qualifier were excluded when determining the range of detected concentrations. However, the data were included when determining the number of detections greater than the MCL.

b. MCL used for comparison is 5 µg/L.

MCL = maximum contaminant level



## 4.27 Additional Ecological Contaminants of Potential Concern

The preliminary ecological contaminant screening identified 56 Waste Area Group 7 ecological contaminants of potential concern (see Section 3.4.2). Of those, 14 are also contaminants of potential concern to human health (see Section 3.4.1). Ecological risk assessments conducted at the INL Site are based on the evaluation and interpretation of the nature and extent of contamination conducted for human health (Van Horn, Hampton, and Morris 1995). No RWMC samples have been collected and analyzed to specifically address ecological receptors, and sampling data collected as part of the human health assessment were not analyzed in terms of nature and extent for individual ecological receptors (e.g., compared to ecologically based screening levels); however, results of biotic sampling conducted as part of INL environmental monitoring programs were used to confirm the transport of contaminants from subsurface-to-surface soil to locations outside the SDA and into the food web.

Soil and biological tissue samples are collected from the SDA and analyzed as part of the following three ongoing programs:

1. Idaho National Laboratory Site environmental surveillance program, overseen by DOE, which includes monitoring areas surrounding INL Site facilities and off-INL Site locations—Results of the environmental surveillance program are published annually. Recent publications are available at the Environmental Surveillance, Education, and Research Program Web site (<http://www.stoller.eser.com>).
2. Environmental monitoring program for non-Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) facility operations, performed by ICP—Methods for collecting and analyzing routine biotic and soil samples are detailed in the Environmental Monitoring Plan for the INL Site (DOE-ID 2004b). Locations at the SDA where samples are collected also are discussed briefly in Section 4.1.3. A summary of environmental monitoring results for 1976 to 1993 is presented in INEL (1995, Appendix F).
3. Monitoring associated with Waste Area Group 7 CERCLA cleanup activities, which also are performed by ICP—Additional sampling, in support of the “Long-Term Ecological Monitoring” Plan (Van Horn, Fordham, and Haney 2004), will be performed at RWMC in FY 2006.

Since 1986, the SDA overburden thickness has been increased with clean soil and substantially recontoured (see Section 3.1.8). Most surface and subsurface soil, vegetation, and animal tissue samples were collected before those modifications (Becker et al. 1998). More recent sampling activities at the SDA have been limited. In addition, composite samples were generally collected for vegetation and tissue, and sampling locations are poorly documented. Because collocated samples were not collected for all media (e.g., both vegetation and soil), exposure factors and concentrations cannot be reconstructed from sampling results. Therefore, the DOSTOMAN model (see Section 5.5) was used to generate concentrations across the SDA to allow evaluation of receptors in terms of a population-level exposure. The model incorporates subsurface-to-surface transport by plant root uptake and animal intrusion (see Section 5.5), and the sampling data presented in the following sections were used as weight of evidence in the ecological risk assessment (see Section 6.6). The data also were used to identify and substantiate the need for analyzing soil and food ingestion pathways. No pathways to groundwater were identified for ecological receptors (see Section 6.6).

The following sections summarize environmental sampling results for the SDA. Results from routine and special monitoring activities are presented for a limited suite of radionuclides (see Section 4.27.1), inorganic constituents (see Section 4.27.2), and organic constituents (see Section 4.27.3) in various media including soil, vegetation, small mammals, and invertebrates.

#### 4.27.1 Radionuclides of Potential Ecological Concern

The preliminary contaminant screening identified 16 radionuclides of potential ecological concern (see Section 3.4.2).

A summary of ICP radionuclide monitoring results for biotic media is given in Table 4-105. Since 1996, vegetation and animal tissue samples have been collected on an irregular basis (mainly because of disturbances resulting from recontouring activities). Therefore, sampling results for 1976 through 1995 reported as part of ICP environmental monitoring are listed on Table 4-105. Maximum concentrations for the most recent analyses for vegetation samples collected in 2001 are Am-241 ( $0.006905 \pm 0.0018$  pCi/g), Pu-239/240 ( $0.0242 \pm 0.0052$  pCi/g), and Sr-90 ( $0.00149 \pm 0.00016$  pCi/g) (DOE-ID 2002). Table 4-106 designates subsections that summarize the results of ICP and CERCLA monitoring for individual radiological contaminants of potential ecological concern that also are of concern for human health.

Table 4-105. Summary of environmental monitoring data collected for radionuclides in and around the Subsurface Disposal Area between 1976 and 1995.

Ecological Contaminant of Potential Concern	Medium Concentration <sup>a,b</sup> ( $\mu$ Ci/g)		
	Surface Soil $\leq$ 10-cm Depth	Vegetation	Tissue (organism)
Am-241	4.0E-08 to $(32.0 \pm 0.6)$ E-06	Below detection limit to $(3.9 \pm 0.6)$ E-08	Below detection limit to $(4.7 \pm 0.3)$ E-07 (mammals)
Cm-244 <sup>c</sup>	NA	NA	NA
Co-60	$(0.77 \pm 0.14)$ E-06	$(0.7 \pm 0.2$ to $1.0 \pm 0.3)$ E-06	$(1.84 \pm 0.18)$ E-06 to $(6.7 \pm 0.7)$ E-07 (mammals)
Cs-137	8.0E-08 to $(0.94 \pm 0.24)$ E-06	$(0.69 \pm 0.19)$ E-07 to $(2.8 \pm 0.2)$ E-04	$(4.1 \pm 0.8)$ E-07 to $(7.32 \pm 0.23)$ E-06
Eu-154	NA	NA	$(7.4 \pm 1.3$ to $39 \pm 3)$ E-07
Tritium <sup>c</sup>	NA	NA	NA
Ni-63 <sup>c</sup>	NA	NA	NA
Pu-238	NA	Below detection limit to $(0.08 \pm 0.01)$ E-06	Below detection limit to $(2.2 \pm 0.2)$ E-07
Pu-239/240	4.0E-08 to $(16.5 \pm 0.8)$ E-06	$(1.0 \pm 0.2)$ E-08 to $(1.05 \pm 0.08)$ E-06	$(2.7 \pm 0.8$ to $30 \pm 2)$ E-08
Sr-90	$(0.11 \pm 0.1$ to $0.6 \pm 0.1)$ E-06	$(9 \pm 2)$ E-08 to $8.7$ E-02	$(2.5 \pm 0.3$ to $6.5 \pm 0.5)$ E-07
U-234	NA	$(2.3 \pm 0.3$ to $3.9 \pm 0.5)$ E-08	$(2.8 \pm 0.4)$ E-08 to $(3.6 \pm 0.4)$ E-07
U-238	NA	$(2.9 \pm 0.4$ to $4.0 \pm 0.6)$ E-08	$(2.5 \pm 0.4)$ E-08 to $(1.2 \pm 0.2)$ E-07

a. Environmental surveillance data reported in INEL (1995).

b. The range encompasses concentrations for all samples collected at the Subsurface Disposal Area. Uncertainties were not reported for some samples.

c. No samples have been collected and analyzed for this ecological contaminant of potential concern.

Table 4-106. Cross references to nature and extent sections for radionuclide ecological contaminants of potential concern.

Ecological Contaminant of Potential Concern	Report Section
Am-241	4.3
Cm-244 <sup>a</sup>	NA
Co-60 <sup>a</sup>	NA
Cs-137 <sup>a</sup>	4.5
Eu-154 <sup>a</sup>	NA
Tritium <sup>a</sup>	4.7
Ni-63 <sup>a</sup>	NA
Pu-238	4.13
Pu-239/240	4.13
Pu-241	4.3
Ra-226	4.14
Sr-90	4.15
U-234	4.18
U-232	4.18
U-238	4.18

a. This contaminant is not a human health contaminant of potential concern.

In addition to ICP routine monitoring, sampling of radionuclides in soil, vegetation, and animal tissue has been conducted in and around RWMC as part of the INL Site environmental surveillance program. A summary of sampling results obtained before major recontouring of the SDA is given in Table 4-107 (Peterson, Brewer, and Morris 1995). In 1998, a special study was implemented to monitor concentration radionuclides in the tissue of marmots inhabiting the SDA (DOE-ID 2004b). Results of the study show concentrations (based on  $3\sigma$ ) of Am-241 (below detection to  $0.004 \pm 0.005$  pCi/g), Co-60 (below detection to  $0.013 \pm 0.012$  pCi/g), Cs-137 (below detection to  $0.405 \pm 0.049$  pCi/g), and Sr-90 (below detection to  $0.016 \pm 0.011$  pCi/g) to be generally decreasing and lower than those previously measured in biota on the SDA. Radionuclide concentrations in small mammals just outside the SDA perimeter measured in 2002 and 2003, as part of a genetic research project, also were shown to be at or below background (Stormberg 2004).

Table 4-107. Summary of environmental surveillance data collected for radionuclides in and around the Subsurface Disposal Area between 1972 and 1987.

Ecological Contaminant of Potential Concern	Medium Concentration <sup>a</sup> (pCi/g)		
	Soil ≤ 10-cm Depth <sup>b</sup>	Vegetation <sup>c</sup>	Tissue (organism) <sup>d</sup>
Am-241	Not detected to 300 <sup>e</sup> Not detected to 51 <sup>f</sup>	0.003 to 5.1 <sup>e</sup>	Not detected to 38 <sup>e</sup> (mammals) Not detected to 270 <sup>f</sup> (mammals) 0.022 ± 0.020 <sup>e,g</sup> (invertebrates)
Cm-244	Not detected to 0.086 <sup>f</sup>	NA	NA
Co-60	0.11 to 62 <sup>e</sup> Not detected to 11 <sup>f</sup>	0.41 to 4.6 <sup>e</sup>	Not detected to 700 <sup>f</sup> (mammals)
Cs-137	Not detected to 2.0 <sup>e</sup> Not detected to 16 <sup>f</sup>	Not detected to 57 <sup>e</sup>	Not detected to 6,200 <sup>e</sup> (mammals) Not detected to 130 <sup>f</sup> (mammals) Not detected to 4.0 <sup>e</sup> (birds) 0.32 ± 0.21 <sup>e,g</sup> (snake) 0.46 ± 0.54 <sup>e,g</sup> (invertebrates)
Eu-154	Not detected to 0.27 <sup>f</sup>	NA	NA
Tritium	NA	NA	NA
Ni-63 <sup>h</sup>	NA	NA	NA
Pu-238	Not detected to 1.4 <sup>e</sup> Not detected to 2.6 <sup>f</sup>	Not detected to 0.057 <sup>f</sup>	Not detected to 8.9 <sup>e</sup> (mammals) Not detected to 41 <sup>f</sup> (mammals) 0.0081 ± 0.011 <sup>e,g</sup> (invertebrates)
Pu-239/240	Not detected to 54 <sup>e</sup> Not detected to 38 <sup>f</sup>	0.002 to 1.9 <sup>f</sup>	Not detected to 3.0 <sup>e</sup> (mammals) Not detected to 5.7 <sup>f</sup> (mammals) 0.078 ± 0.11 <sup>e,g</sup> (invertebrates)
Sr-90	Not detected to 4.6 <sup>e</sup> Not detected to 26 <sup>f</sup>	Not detected to 160 <sup>f</sup>	Not detected to 3,500 <sup>e</sup> (mammals) 2.4 ± 3.2 <sup>e,g</sup> (invertebrates)
U-234 <sup>h</sup>	NA	NA	NA
U-238 <sup>h</sup>	NA	NA	NA

a. Environmental surveillance data reported in Peterson, Brewer, and Morris (1995).

b. Samples were collected at various locations at and near the SDA between 1972 and 1985.

c. Samples were collected at various locations at and near the SDA between 1976 and 1982.

d. Samples were collected at various locations at and near the SDA between 1978 and 1987.

e. The range encompasses concentrations for all samples collected at the SDA. Uncertainties were not reported for most samples.

f. The range encompasses concentrations for all samples collected at and beyond the SDA perimeter. Uncertainties were not reported for most samples.

g. Concentration does not meet the 3σ criterion for a positive detection (see Section 4.15).

h. No samples have been collected and analyzed for this ecological contaminant of potential concern.

SDA = Subsurface Disposal Area

#### 4.27.2 Inorganic Ecological Contaminants of Potential Concern

The screening identified 20 inorganic ecological contaminants of potential concern (Section 3.4.2). Soil samples have been collected at the SDA and analyzed for cadmium, lead, manganese, and nitrate. Results are shown in Table 4-108.

Table 4-108. Inorganic ecological contaminants of potential concern and soil sample analyses.

Ecological Contaminant of Potential Concern	Waste Area Group 7 Sample 7 <sup>a</sup>		Environmental Monitoring <sup>b</sup>	
	Number of Detections/ Number of Samples	Range (mg/kg)	Number of Samples	Range (mg/kg)
Aluminum nitrate	NA	NA	NA	NA
Beryllium	NA	NA	NA	NA
<b>Cadmium</b>	25/79	0.7 to 2.3	Not reported	1.9 to 2.7
Chromium	See Section 4.20	See Section 4.20	NA	NA
<b>Lead</b>	71/79	0.84 to 26	Not reported	8.8
Lithium hydride	NA	NA	NA	NA
Lithium oxide	NA	NA	NA	NA
<b>Manganese</b>	66/79	164 to 869	NA	NA
Magnesium oxide	NA	NA	NA	NA
<b>Nitrate</b>	See Section 4.19	See Section 4.19	NA	NA
Potassium chloride	NA	NA	NA	NA
Potassium hydroxide	NA	NA	NA	NA
Potassium nitrate	NA	NA	NA	NA
Potassium phosphate	NA	NA	NA	NA
Potassium sulfate	NA	NA	NA	NA
Sodium chloride	NA	NA	NA	NA
Sodium hydroxide	NA	NA	NA	NA
Sodium nitrate	NA	NA	NA	NA
Sodium phosphate	NA	NA	NA	NA
Sodium-potassium	NA	NA	NA	NA

Note: **Bolded text** indicates contaminants for which soil samples have been collected and analyzed.

a. Data are contained in Idaho Cleanup Project monitoring databases.

b. Sample analysis data were obtained from INEL (1995, Appendix F).

c. Detection resulted from drilling adjacent to the Acid Pit.

#### 4.27.3 Organic Ecological Contaminants of Potential Concern

The preliminary contaminant screening identified 20 organic ecological contaminants of potential concern (see Section 3.4.2). Routine data for these contaminants of potential concern have not been collected. Most surface soil samples have been collected from areas near the Acid Pit and Pad A and analyzed for seven of the 20 ecological contaminants of potential concern (shown in Table 4-109). Sampling results for carbon tetrachloride and methylene chloride are presented in detail in Sections 4.22 and 4.24, respectively.

Table 4-109. Summary of organic ecological contaminants of potential concern and soil sample analyses.

Ecological Contaminant of Potential Concern	Number of Detections/ Number of Samples <sup>a</sup>	Range (mg/kg)
1,1,2-Trichloro-1,2,2-trifluoroethane	NA	NA
1,4-Dioxane	NA	NA
3-Methylcholanthrene	NA	NA
Alcohols	NA	NA
<b>Carbon tetrachloride</b> (see Section 4.22)	3/103	6 to 11
Dibutylethylcarbutol	NA	NA
Ether	NA	NA
Hydrofluoric acid	NA	NA
<b>Methylene chloride</b> (see Section 4.24)	60/103	7 to 139
<b>Nitrobenzene</b>	0/68	NA
Nitric acid	NA	NA
<b>Organophosphates (tributylphosphate)</b>	1/68	590
Organic acids (ascorbic acid)	NA	NA
Sulfuric acid	NA	NA
Tetrachloroethylene (see Section 4.25)	NA	NA
Trichloroethylene (see Section 4.26)	NA	NA
Trimethylpropane-triester	NA	NA
<b>Toluene</b>	2/103	23 to 28
Versenes (ethylenediaminetetraacetic acid)	NA	NA
<b>Xylene</b>	0/103	NA

Note: **Bolded text** indicates contaminants for which soil samples have been collected and analyzed.

a. Data contained in Idaho Cleanup Project monitoring databases.

## 4.28 Nature and Extent of Contamination Summary

Tens of thousands of samples have been collected in the proximity of RWMC and the SDA over the past 33 years, and more than 100,000 analyses have been performed. Subsurface soil, interbed sediment, basalt, soil moisture (pore water), soil gas, perched water, and the aquifer are monitored regularly. Surface soil, flora, fauna, air, and run-off water around RWMC also are monitored routinely by the INL Site Environmental Surveillance Program. Numerous studies also have been conducted over the years. Analytical data associated with contaminants of potential concern at RWMC were compiled and evaluated. The compilation encompasses analytical data from 1971 to 2004 and includes results generated by DOE, USGS, and the various INL Site contractors. In addition to the contaminants of potential concern, constituents that are frequently detected or provide good tracers for assessing transport in the vadose zone also are discussed and summarized.

Monitoring at RWMC has been conducted over time under a variety of programs and with differing objectives. Locations for monitoring capabilities, such as aquifer monitoring wells, vadose zone lysimeters, and waste zone probes, were chosen based on individual program objectives. One thing all programs had in common was that monitoring locations were specifically selected to maximize the likelihood of detecting contamination. Though the network is biased toward detection, detections still are generally sparse and sporadic, typically near detection levels, with only a few trends limited to only a couple of specific locations in the shallow vadose zone. Source-term inventories originate in the waste zone and become contaminants if they migrate into the environment. A few contaminants are detected in the vadose zone, and some are migrating. Approximately 65% of all radionuclide detections in vadose zone soil moisture occur in the depth interval above the B-C interbed (0 to 84 ft); 25% of the detections occur in the depth interval encompassing the B-C interbed (84 to 141 ft); 9% occur in the C-D interbed (214 to 257 ft), and less than 1% are found beyond the C-D interbed. These detection frequencies show that interbeds provide a good filter or capture zone for water and migrating contaminants. Migration is very limited with no imminent threat to the aquifer except for carbon tetrachloride, a VOC associated with Rocky Flats Plant weapons-production waste. A more detailed summary is provided below and is organized in a tiered fashion from the surface of RWMC area to the aquifer beneath RWMC (e.g., waste zone, surface, vadose zone, and aquifer).

### 4.28.1 Waste Zone

Waste zone data are relatively sparse because of the hazards associated with obtaining data directly from buried waste. Though samples were obtained from Pit 9, most data are generated through monitoring of Type B probes in a few focus areas. As expected, concentrations in these focus areas within the buried waste are high, demonstrating success in choosing locations for waste zone monitoring. Constituents detected most frequently in the waste zone include (listed in order of detection frequency):

1. Volatile organic compounds
2. Plutonium isotopes
3. Americium-241
4. Uranium isotopes.

Relatively high concentrations of carbon tetrachloride, tetrachloroethylene, and trichloroethylene are routinely detected in samples collected from Type B vapor probes. Very high concentrations of organic compounds, plutonium, and americium were detected in soil-moisture samples collected from the Depleted Uranium Focus Area in 2004. Samples from the Americium/Neptunium Focus Area contained uranium, plutonium, neptunium, and americium; samples obtained in the Organic Sludge Focus Area

showed plutonium and uranium. Analytical indicators (e.g., plutonium isotope activity ratios and ratios of various organic compounds) show the sampled areas are primarily composed of weapons manufacturing waste from Rocky Flats Plant.

In general, constituent profiles and ratios confirm successful penetration of waste types that were targeted in each focus area. For example, organic compounds and radionuclides detected in the Depleted Uranium Focus Area in 2004 were compared to waste disposal inventories in this area, and good correlation was noted.

#### **4.28.2 Surface**

Hundreds of surface soil, vegetation, and run-off water samples have been collected and analyzed for numerous analytes over the past 10 years. Most constituents at RWMC are measured at concentrations near surficial soil background levels, and none have exceeded soil RBCs. Of the contaminants of potential concern, Pu-239/240 and Am-241 are the most frequently detected in surface soil samples inside and outside the SDA, at detection rates of about 22 and 21%, respectively. The high number of Pu-239/240 detections compared to Pu-238 suggests the plutonium is either from weapons-manufacturing waste in the SDA or from fallout. Americium-241 and Pu-239/240 concentrations are generally low; however, the fact that these contaminants are present at detectable levels in the surface environment around the RWMC area emphasizes the importance of following radiological control procedures to minimize cross-contamination when drilling and installing new monitoring wells and collecting samples. The presence of surface contamination outside the SDA also substantiates the likely origin of Pu-239/240 detected during well drilling, installation, and aquifer sampling in the early 1970s. Detections in samples of vegetation and run-off water were few, and their contributions to the assessment of Pu-239 concentrations were insignificant.

#### **4.28.3 Vadose Zone Soil Moisture and Perched Water**

Various radionuclides and chemicals are detected in the vadose zone. Most are detected only sporadically and have no associated temporal or spatial trends. Contaminants of potential concern that have been consistently detected in the vadose zone (see Figure 4-92), exhibit concentration trends, and show evidence of migration are listed below in order of detection frequency from highest to lowest:

1. Volatile organic compounds
2. Uranium isotopes
3. Nitrate
4. Technetium-99
5. Carbon-14.

Other constituents that are not contaminants of potential concern, but are regularly detected in concentrations greater than aquifer background values, are, in order of detection frequency from highest to lowest: tritium and chemical constituents of magnesium chloride brine.

High concentrations of VOCs are routinely detected in perched water and lysimeters samples because these compounds migrate rapidly in the vapor phase and are also soluble. Because of this, VOCs are not shown in Figure 4-92. Concentration increases of other contaminants at some locations in the vadose zone are changing rather quickly. An example of fast-changing concentrations, or migration, is nitrate at Lysimeters PA02, I2S, and I4S.



Intermittent detections of radionuclides in the vadose zone occur (in order of detection frequency from highest to lowest) for Sr-90, Cl-36, Pu-238, Am-241, I-129, and Pu-239/240. The highest density of frequent detections is in the vicinity of the B-C interbed; however, some detections occur in the vicinity of the C-D interbed. Analytical evidence shows that intermittently detected contaminants are not widespread in the vadose zone, nor are they migrating at measurable concentrations.

**4.28.3.1 Volatile Organic Compounds.** Carbon tetrachloride, tetrachloroethylene, and trichloroethylene are consistently detected in perched water and lysimeter samples. Each has been detected above MCLs in perched water samples and in shallow, intermediate, and deep lysimeter samples. Methylene chloride is detected less frequently and at lower concentrations. Methylene chloride has been detected in shallow lysimeter and perched water samples above the MCL, but has not been detected in any intermediate or deep lysimeter samples.

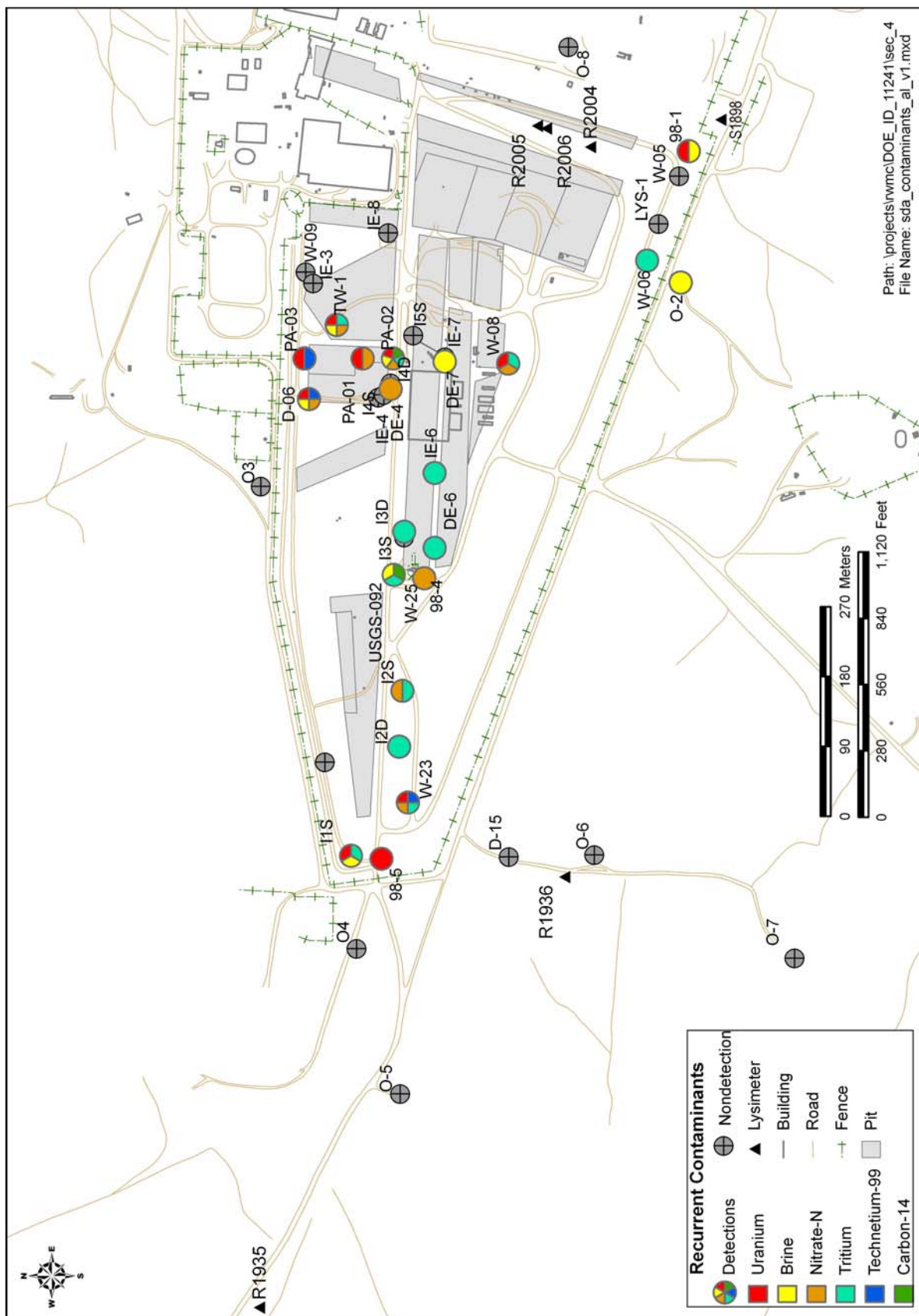
**4.28.3.2 Uranium Isotopes.** Uranium concentrations in all but one location in the vadose zone and aquifer are consistent with naturally occurring uranium, though numerous vadose zone soil-moisture samples significantly exceed local soil moisture background levels. The one exception, TW1:DL04 in Pit 5 near Pad A, exhibits concentrations and isotopic ratios that clearly indicate uranium at this location is anthropogenic and slightly enriched with U-235. This interpretation is further supported by thermal ionization mass spectrometry analysis of a TW1 sample in 1999 (Roback et al. 2000).

Concentrations exceeding local background levels are most prevalent in shallow and intermediate depths of the vadose zone near three specific areas in the SDA: around Pad A and Pit 5, the western end of the SDA, and the Acid Pit. Though elevated levels of uranium at these locations are within the range of naturally occurring uranium, other contaminants also are detected in these same locations, indicating some migration may be influencing sample results.

**4.28.3.3 Nitrate.** Nitrate concentrations at many monitoring locations are above the local soil moisture upper background range; however, because of background variability, only five monitoring locations have concentrations high enough above the upper background range to confidently declare nitrate is likely from anthropogenic sources (i.e., Wells D15, I2S, W08, W25, and 98-4). The high nitrate concentrations are predominantly found in shallow and intermediate-depth intervals. Concentration trends are evident at monitoring Lysimeters I2S, PA02, and W25, which are located by Pad A and in the western part of the SDA at depths around 30.5, 2.7, and 4.9 m (100, 9, and 16 ft), respectively (see Figure 4-92). Nitrate measured at Lysimeter PA02 by Pad A appears to be migrating downward because concentrations at Well I4S, about 30.5 m (100 ft) below Pad A, have started increasing.

**4.28.3.4 Technetium-99.** Technetium-99 is consistently detected at depths to 27 m (88 ft) in Well D06 by Pad A and Well W23 at the western end of the SDA (see Figure 4-92). The concentration associated with Well D06 is increasing. Because of its solubility, mobility, depth of detection, and frequency of detection at certain locations, Tc-99 possibly is more prevalent in the vadose zone than indicated by monitoring data. Historically, Tc-99 has not been a target for vadose zone investigation or an analytical priority. Therefore, monitoring capability is sparse in some areas where Tc-99 has been buried.

**4.28.3.5 Carbon-14.** Carbon-14 concentrations around the beryllium blocks are substantially higher than C-14 concentrations near the activated steel or LLW disposals. Carbon-14 is detected intermittently in soil-moisture samples (see Figure 4-92) but is readily detected in vapor samples collected near beryllium blocks and activated stainless steel and is also detected in vapor samples collected from OCVZ vapor ports at depths from 11 to 51 m (35 to 166 ft).



Collecting C-14 samples with suction lysimeters (vacuum) may volatilize the C-14 and produce nondetections or biased-low concentrations. This may explain why C-14 is only intermittently detected in soil-moisture samples.

#### **4.28.4 Vadose Zone Cores**

Few radionuclides are detected in core samples. Most are detected only sporadically and have no associated temporal or spatial trends; radionuclides consistently detected in RWMC core samples are listed below in order of detection frequency:

1. Technetium-99
2. Americium-241
3. Plutonium-239/240
4. Strontium-90
5. Plutonium-238.

Sample concentrations are generally very low and below soil RBCs used for comparison. Americium-241, Pu-238, and Pu-239/240 were primarily detected in the 0 to 35-ft and 35 to 140-ft depth intervals, with very few detections at depths greater than 140 ft. Concentrations of these actinides ranged from 0.002 to 9.6 pCi/g, with a mean concentration around 0.25 pCi/g. Most Am-241 detections were not corroborated with detections of other actinides (e.g., Pu-238 and Pu-239/240) except at monitoring locations in Pit 5, where Pu-238 and Pu-239/240 also were detected. The majority of valid plutonium and americium detections (i.e., those not taken between 1971 and 1974) are located in the Pit 5 area (i.e., Wells 79-2, D02, and TW1) and the western part of the SDA (i.e., Wells 76-3, 76-4, 78-5, I-1S, I-2S, I-3S, USGS-93, and USGS-96). Figure 4-93 shows locations where core samples have been collected and contaminants have been detected. All plutonium detections in the 35 to 140-ft depth interval occurred between 30 and 34 m (98 and 111 ft), which is the location of the B-C interbed. This substantiates the conclusion by Batcheller and Redden (2004) that plutonium (and probably other contaminants) is effectively immobilized in sedimentary interbeds.

Detections of Tc-99 in the I-series wells in 1999 were not corroborated by detections in the 2003 core sampling campaign. Some evidence supports a conclusion that Tc-99 is present, and some evidence is to the contrary. However, lysimeter data imply Tc-99 transport may be occurring.

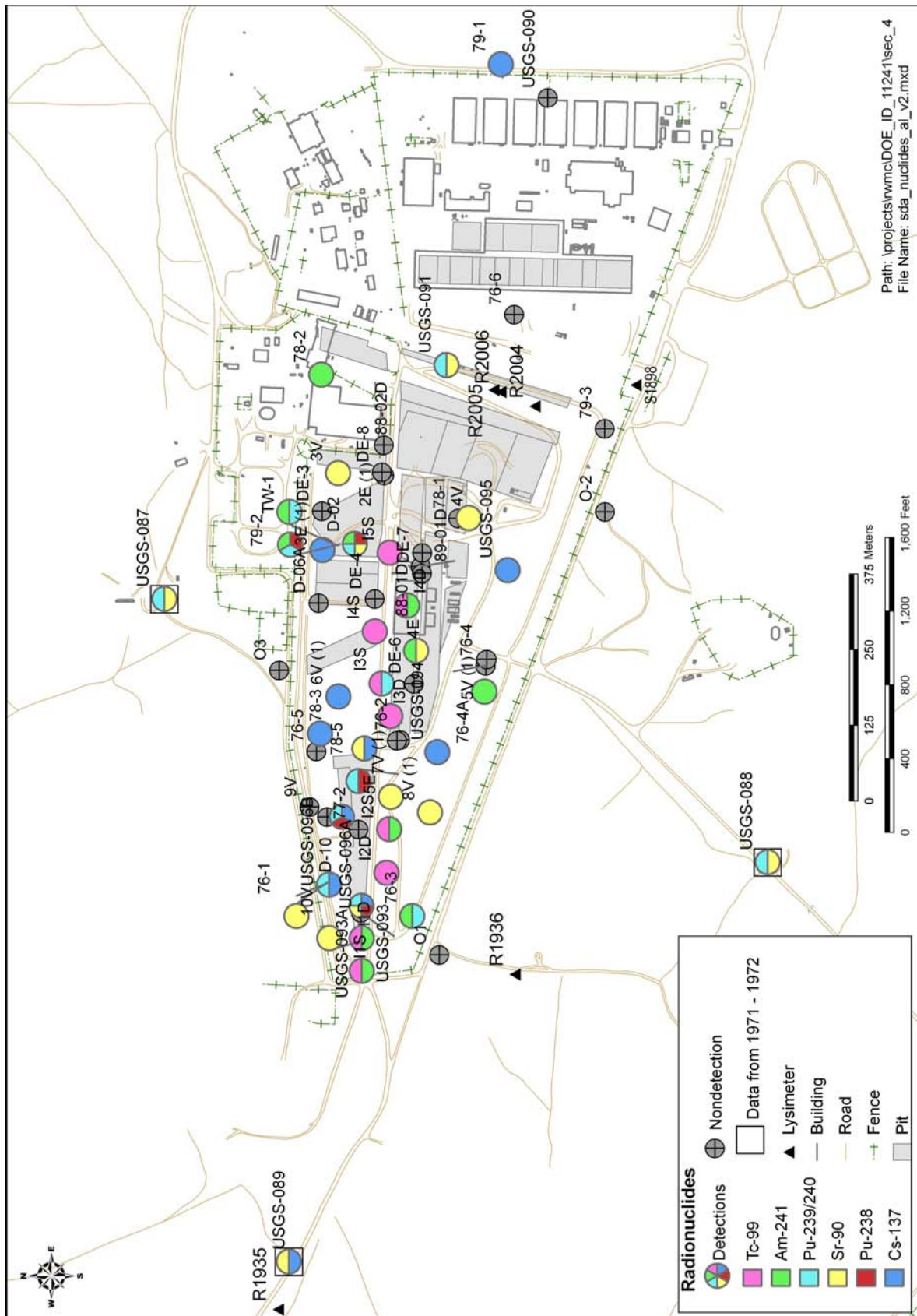


Figure 4-93. Detected radionuclides in core samples between 1971 and 2003.

#### **4.28.5 Vadose Zone Soil Gas**

Volatile organic compounds are consistently detected in soil gas samples from land surface to the aquifer and as far as 1 km (3,281 ft) beyond the SDA. Thousands of gas samples have been collected from over 100 permanent soil-gas sampling ports inside and outside the SDA. The compounds are analyzed with an instrument that measures concentrations of the five compounds listed below, and are presented in order of highest-to-lowest average concentration:

1. Carbon tetrachloride
2. Chloroform
3. Trichloroethylene
4. 1,1,1-Trichloroethane
5. Tetrachloroethylene.

Except for chloroform, these are the primary volatile organic constituents in Series 743 sludge. Very little chloroform was buried in the SDA; but because it is a degradation product of carbon tetrachloride, it is ubiquitous in the soil gas. Soil-gas samples are not analyzed for methylene chloride and 1,4-dioxane.

Concentrations of VOCs in soil gas have been reduced by the OU 7-08 vapor vacuum extraction with treatment system that has been in operation since 1996. Concentrations near active source areas have been less impacted by the remediation system.

#### **4.28.6 Aquifer**

Very few radionuclides or chemicals are regularly detected at levels greater than background concentrations or MCLs in the aquifer beneath RWMC. The only contaminants of potential concern frequently detected in the aquifer near RWMC are listed below in order of detection frequency from highest to lowest:

1. Carbon tetrachloride
2. Trichloroethylene
3. Uranium isotopes
4. Cesium-137.

Other constituents that are not contaminants of potential concern, but are regularly detected in concentrations greater than aquifer background values, in order of detection frequency from highest to lowest, are tritium, sulfate, chloride, chromium, toluene.

Intermittently detected in the aquifer near RWMC, in order of detection frequency from highest to lowest, are bromide (not a contaminant of potential concern), magnesium (not a contaminant of potential concern), carbon-14, nitrate, plutonium-238, americium-241, plutonium-239/240, methylene chloride, and tetrachloroethylene. Detection frequencies are low. For example, plutonium (i.e., Pu-238 plus Pu-239/240) detections occur at a rate of 1.0%, which is slightly lower than the detection rate of blank samples (1.2%) and is also the number of times a result is expected to occur outside the 99.7% confidence interval (i.e., a false positive detection).

The only contaminant of potential concern that impacts the aquifer beneath RWMC is carbon tetrachloride, which is consistently detected in numerous aquifer monitoring wells at concentrations near and occasionally greater than the MCL of 5 µg/L. Toluene and trichloroethylene also are detected frequently at certain locations in the aquifer beneath the SDA, but concentrations are significantly less than MCLs and concentration trends are not evident. Low levels of tritium, chromium, and nitrate, as well as a few anions and cations, are detected consistently above background levels in the aquifer beneath RWMC; however, the source of these constituents is uncertain—in addition to potential transport from the SDA, contributions from upgradient facilities or corroding well construction material could be factors.

Analytical evidence shows intermittently detected contaminants (i.e., C-14, nitrate, Pu-238, Am-241, Pu-239/240, methylene chloride, and tetrachloroethylene) are not widespread in the aquifer near RWMC, and they are not migrating at measurable concentrations. Nitrate concentrations in monitoring Well M6S are higher than all other RWMC aquifer monitoring wells; however, the long-term trend appears to have leveled off at concentrations near the upper background range.

Segregation in the aquifer is observed around RWMC. Tritium detections only occur in monitoring wells north of RWMC; high anions and cations (i.e., chlorine, bromine, sulfate, magnesium, and nitrate) are found in wells south of RWMC. Trichloroethylene and toluene are located to the east and south, and high chromium concentrations are isolated to the low-permeability zone beneath the southern RWMC boundary. Excluding VOCs, upgradient concentrations are attributable to other facilities (see Section 2.3.4).

**4.28.6.1 Carbon Tetrachloride.** Low levels of carbon tetrachloride are consistently detected in aquifer monitoring wells in and around RWMC (see Figure 4-94). The maximum concentration was 8 µg/L measured in Well M7S. Concentration trends of carbon tetrachloride in many RWMC aquifer monitoring wells appear to be stabilizing and perhaps declining slightly; however, concentrations in Wells M7S, M16S, RWMC Production Well, and A11A31 continue to fluctuate slightly above and below the MCL of 5 µg/L. No wells exhibited an obvious increasing trend over the past few years, but Well USGS-120 has shown a decreasing trend.

**4.28.6.2 Trichloroethylene.** Trichloroethylene is routinely detected at low levels in aquifer monitoring wells in and around RWMC (see Figure 4-94). The maximum concentration was 3.9 µg/L measured in Well USGS-90 in 1988. Since 2000, the highest concentrations measured were 3.3, 3.2, and 3.0 µg/L in Wells RWMC Production, A11A31, and M7S, respectively. Concentration trends of trichloroethylene in most RWMC aquifer monitoring wells are stable. Trichloroethylene has not been detected in the aquifer greater than the MCL of 5 µg/L.

**4.28.6.3 Uranium Isotopes.** Uranium detections in aquifer monitoring wells are consistent with natural background values and have never approached or exceeded the MCL for total uranium. The number of detections of U-233/234 and U-238 exceeding the upper background comparison concentrations are consistent with expected rates (i.e., less than or equal to 1%). The detection rate for U-235/236, which is slightly higher than those for U-233/234 and U-238, is attributed to (1) relatively high measurement uncertainties associated with low-level U-235/236 analyses and (2) a low upper background comparison concentration at RWMC (ranges at other aquifer monitoring locations around the INL Site are typically a factor of two higher than at RWMC).

**4.28.6.4 Cesium-137.** The detection rate of Cs-137 for aquifer samples is also very low (i.e., 1.5%), but slightly higher than the expected rate. Many of the detections contributing to the detection rate occurred in the early 1970s and are artifacts of well drilling and sampling methods employed at the time. The MCL was exceeded in one aquifer sample collected in 1995; however, Cs-137 has not been detected at that sampling location in subsequent sampling events.



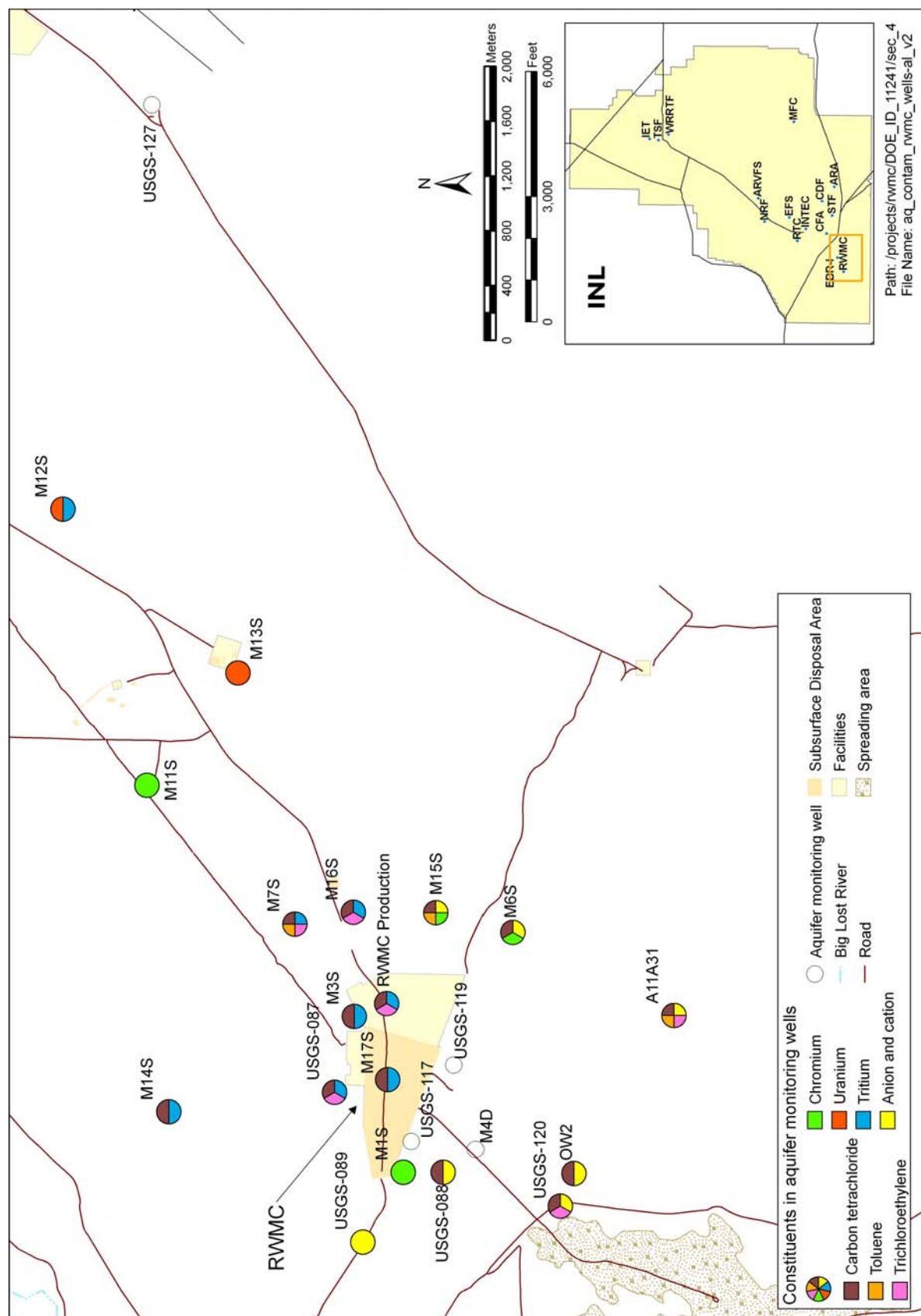


Figure 4-94. Constituents in aquifer monitoring wells.